An Assessment of the Long-Term Changes in Chondrichthyan Abundance on the Inshore Trawl Grounds of the Agulhas Bank, South Africa

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To institutions, for data transformed beyond recognition;

To mom and dad, who supported in times of desperation;

To friends, who aided when faced with academic stagnation;

To my supervisor, who advised on many an occasion;

To my brother, despite being from a different vocation

For his in-depth participation,

And insights which were valued beyond summation;

For all you I write this dedication.

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Abstract

Trawl fisheries have been operating in South African waters for roughly 110 years. In contrast to other trawl fisheries, the South African fishery was opened by government-funded scientific trawl surveys beginning in 1898. Detailed records of survey trawls undertaken immediately prior to and during the beginning of commercial trawling activity provided a rare opportunity to examine long-term changes in fish abundance. This dissertation focuses on the chondrichthyans, which are believed to be the group of fishes most at risk from intense exploitation. Despite some problems associated with changes in taxonomy and the efficiency of gear, this analysis was able to compare two distinct periods at three taxonomic levels: The periods were taken to represent baseline values prior to the opening of trawl fisheries and contemporary data, separated by roughly 80 years of intense, trawling activity. Three historically important trawl grounds were identified as having sufficient samples from each period. Between the surveys, trawl velocity did not deviate much from contemporary trawl velocities, although all surveys were found to have a significantly different velocity. In respect to the catch composition, significant changes were found in the relative abundance of the total catch composition, as a general shift from large, long-lived species towards smaller species was found. This applied both for teleosts as well as chondrichthyans, with the entire chondrichthyan catch composition showing a decrease, with the exception of *Callorhinchus capensis*, which increased significantly. Changes in chondrichthyan swept-area density were found to follow those trends found in the relative abundance: An increase was found in *Callorhinchus capensis*, whereas all other species decreased. All chondrichthyans were classed in low productivity categories and were assigned a high risk factor to overfishing. Reasons for the declines in the chondrichthyan assemblage were low fecundity, slow maturation and the inability due to these factors to adapt to an environment altered by trawling. Only in the case of *Callorhinchus capensis* were secondary effects of trawling such as the removal of competitor species likely to have caused the increase in relative abundance and swept area density as well as *Callorhinchus capensis* having a relatively high fecundity among chondrichthyans. In general, chondrichthyan decreases exceeded those of teleosts, and this work provides broad empirical support for the hypothesis that the low fecundity and slow growth of chondrichthyan species places this group at higher risk than teleosts.

CHAPTER 1: INTRODUCTION

Industrial trawl fisheries in South Africa began in the late 1800s. Prior to 1890, when a few entrepreneurs began towing trawl nets with tugboats in close-shore waters, the markets along the coast were supplied almost exclusively by linefishermen. However, with the advent of diamond and gold mining (1867 and 1886), the Boer Wars (1880-1881 and 1899-1902) and the outbreak of World War One (1914), the need arose to feed the increasing number of people streaming into the country.

It was realised that agriculture and farming alone would not cover the rising demand for food. Therefore, the government looked to establish fisheries modelled after the North American and United Kingdom trawl fisheries to overcome the deficit in supply (Gilchrist, 1898). Charged by the government to locate fishing grounds, surveys conducted by the *FRV Pieter Faure* opened up grounds that the fledgling trawl industry then exploited, pioneering the fish market to the South African interior and later the world with a varied range of internationally competitive fish products (Sauer et al. 2003). Hence, the trawl fisheries of South Africa did not follow a natural development from a small-scale, subsistence fishery into a large, industrial fishery. Rather, following the government surveys the fishery developed rapidly to an industrial-scale fishery within a few years.

At the beginning of industrial scale exploitation, trawling was confined to close inshore waters due to the size and power of the vessels. Driven by steam engines, they did not have the power to deal with the open sea beyond the relatively sheltered close inshore areas. Furthermore, large scale ice production methods were not implemented until the late 1930s, limiting the time that a ship could stay at sea and keep a catch fresh.

Initial surveys were therefore first concentrated as close as possible to the centres of consumption: for example in False Bay, where it was soon realised that trawling was not worth the fishing effort. The surveys then moved west, where West Coast sole (or “super sole”, *Austroglossus microlepis*) was targeted due to its high economic value. These grounds were soon depleted as they were relatively small and unproductive. Exploration then moved east along the South Coast, still targeting species of sole (*A. microlepis* and *A. pectoralis*). In 1898 the surveys opened up the Cape Infanta and Mossel Bay grounds in close proximity to the coast. Similar efforts opened grounds in Algoa Bay and East London near fledgling metropolitan areas.

It is noteworthy that during the early phases of exploitation, hake (*Merluccius capensis*) was not considered to be the primary catch. Primary targets were sole (*Austroglossus spp*.) and silver kob

(*Argyrosomus inodorus*). Only later, during World War One, was it recognised as a potential target specie and was fished as the main target fish from about 1929 onwards (Scott, 1949).

Present-day trawl fisheries in South Africa

Today, the modern trawl fishery in South African territorial waters is divided into the following sectors:

Firstly, off both the South and West Coasts of South Africa, a deep-water trawl fishery targets deep-water hake (*Merluccius paradoxus*) and monkfish (*Lophius vomerinus*) in waters from 110 m to 500 m depth.

Secondly, the inshore trawl fishery is confined to depths of less than 110 m on the South Coast. It has two components, managed separately (Attwood & Peterson, 2010). One targets shallow-water hake (*Merluccius capensis*) and the other targets East Coast sole (*Austroglossus pectoralis*) (Kroese et al. 1995; Sauer et al. 2003; Walmsley et al. 2007a). Ships are allowed to target only one of the two, as permits are species specific and quotas are applied (DAFF, 2009).

The dividing boundary between the two trawl fisheries is the 110 m isobath or 20 nm offshore, whichever is the furthest from the coast (DAFF, 2009). This is in order to limit the impact of large, offshore ships and gear in the inshore zone, where the ecological effects of trawling are expected to be greater (Attwood & Peterson, 2010). However, there is some overlap between the offshore and inshore fisheries, as some of the larger inshore trawlers also operate in the offshore areas. Inshore trawlers are not allowed to trawl in the closed areas that include bays and the marine protected areas of De Hoop and Tsitsikamma, as well as the sanctuary of Bird Island in Algoa Bay (DAFF, 2009).

The inshore fishery

The main fishing effort takes place on the border of the inshore and offshore grounds, around the 110 m isobath, predominantly in three main inshore fishing grounds: the Cape Infanta ground, the

Blues Bank off Mossel Bay and the Algoa Bay ground. Both the Mossel Bay and the Blues Bank are generally hake grounds, whereas sole is targeted on the Chalk Line ground south west of Algoa Bay (Figure 1). The ships operate from both Mossel Bay (90%) and Port Elizabeth (10%), where they form a significant part of the local economies (Sauer et al. 2003). The prevalence of ships in Mossel Bay depends on the abundance of sole, with some Port Elizabeth-based trawlers moving east when sole is abundant there (Sauer et al. 2003; Walmsley et al. 2007b).

As the largest part of total fisheries, the inshore and offshore trawl fisheries combined generate the majority of the income in the South African fishing industry. Of all South African fishing sectors, trawling is the only one to supply permanent, formal employment to its workers, both shore-based and sea-based and all fisheries together pay salaries much better than most other industries (Sauer et al. 2003).

By international standards, both the inshore and offshore fleets are considered old. The average age of the inshore fleet in the year 2000 was 24 years. Although there were some relatively “new” vessels in the fleet, the majority of the inshore fleet was over 30 years old. Twenty-four of the 29 inshore vessels were less than 25 m in length and under 100 t gross registered tonnage. The vessels smaller than 20 m tended to target and catch more sole, whereas the larger ones targeted and caught more hake. Trips lasted for about 7 to 10 days, depending on the size of the ship, the target catch and fishing success (Sauer et al. 2003). The boats were crewed by 15 to 30 men (Scott, 1949; personal observation).

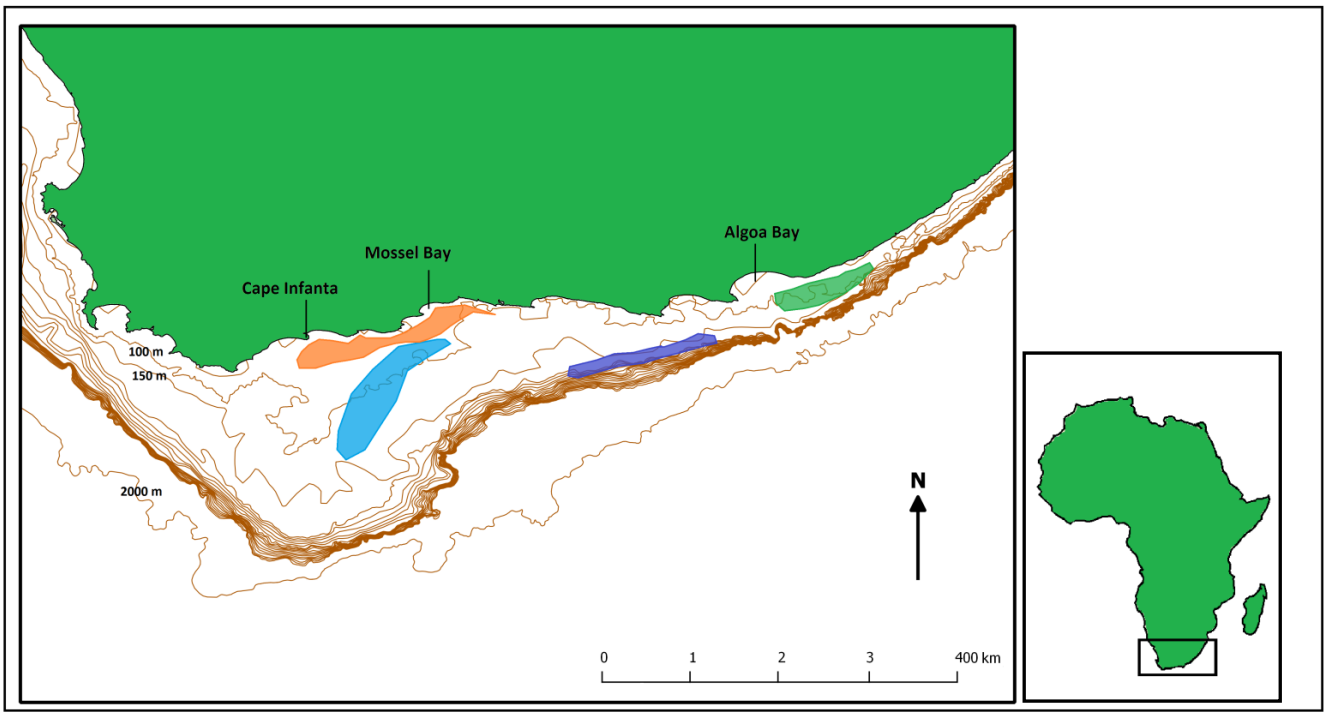


Figure 1: The area of Agulhas Bank and the location of the main contemporary trawl grounds off the South Coast of South Africa. Blue=Blues Bank, Orange= Mossel Bay, Green= Algoa Bay, Purple= Chalk Line.

Biogeography

Survey data used by Smale & Badenhorst (1991) suggested that there was one single inshore fish community. However, Walmsley et al. (2007b) found that there were two communities, with the boundary being the 22° east parallel. Likewise, the sole fishing grounds were found to have a significantly different community structure to that of the remaining grounds on the Agulhas Bank. The authors found that this significance was caused primarily by shoaling species (e.g. *Lepidopus caudatus and Trachurus capensis*), which were either present in the catch in great numbers or absent. Walmsley et al. (2007b) concluded that these shoaling species and the targeted bycatch contributed the largest differences in the estimates of catch and discarding between the datasets and grounds, posing a problem when it came to stock analysis. The authors subsequently suggested that two fishing management units, one sole and one hake, would be needed to ensure sustainable management over the ecologically different areas.

Surveys

The first official survey of the benthic and bentho-pelagic community was done by Gilchrist, the first government marine biologist based in Cape Town. The surveys ran from 1898 to 1904 using the *FRV Pieter Faure*, a purpose-built ship (Scott, 1949). These surveys were responsible for charting new fishing grounds for commercial trawling. Reports of detailed surveys were made available to the fishing industry in order to promote the new grounds and trawl fishing. After a break in the surveys corresponding to an economic recession and World War One, surveys were resumed in 1920 using the *SS Pickle* and continued with the *FRV Africana* until the year 1948. The government survey series resumed in 1985 and continues until the present.

A small mesh survey was conducted in 1980 by Wallace et al. (1984). The primary objective of this one-year survey was to identify nursery areas of the inshore environment that especially commercially exploitable fish species were using as breeding and nursery grounds.

A ship-based observer programme was initiated in 1996, to quantify pre-discard catches and the extent of dumping in the inshore trawl fishery. This programme ran in two phases, the more substantial second phase covering the years 2002 to 2006. Observers were randomly deployed on inshore vessels. Two sampling protocols were followed: firstly, observers took a random, pre-sorting sample of the catch by either placing a bin under the net prior to the opening of the cod-end, or by filling a bin once the catch had been emptied on deck, prior to sorting. Secondly, the crew were asked to set the discards aside for sampling. These two sampling methods usually did not occur on the same net haul. All species in the samples were identified, their total length measured, and weight estimated. Samples were then scaled up to either the total catch or total discard per trawl (Attwood, et al. 2011).

Management of target species

The inshore trawl industry is generally compliant with current legislation. This is due to controls at the ports, limited landing points due to the nature of the South African coastline and a reasonably good observer network (Sauer et al. 2003). As offshore trawlers are excluded from fishing inshore, they cannot impact on inshore fisheries monitoring and statistics (DAFF 2009).

The hake quota is given as a "global quota" for both hake species, *Merluccius capensis* and *M. paradoxus*, meaning assessment of the resources is handled as if both stocks belonged to a single specie (Walmsley et al. 2007b). The hake quotas are subject to review and amendments each year with respect to the stock size and health of the hake (Sauer et al. 2003; Walmsley et al. 2007a).

The catch in the trawl fisheries is managed by Total Allowable Catch limits (TAC) and effort is capped (Total Allowable Effort, TAE) for the inshore sector, keeping large, offshore vessels away from the inshore trawling grounds. The hake and sole trawl fishery has no seasons, but there are Marine Protected Areas where the trawlers may not fish. The mesh size is restricted to 75 mm in the cod-end (stretch size).

There are some disadvantages to these management policies. Total Allowable Catch promotes discarding and highgrading. There is concern that especially hake (*Merluccius spp.*) may be highgraded. Total Allowable Effort has the disadvantage of "creeping effort": Fishing technology is constantly improving, and the TAE value may not reflect or represent the true efficiency of an upgraded fishing vessel anymore (Branch & Clark, 2006).

Bycatch and discards

The term "bycatch" has many connotations. Quantifying bycatch levels is complicated by the term being widely used and having many definitions (Walmsley et al. 2007a; Walmsley et al. 2007b). It is often referred to as the incidental, non-target catch. However, it also encompasses fish that have economic value and may be retained although they are non-target catch. A specie which is unmarketable or unusable due to regulatory or economic reasons and is subsequently removed from the catch is also termed a discard. Discards are thrown overboard, usually dead or unable to survive due to injuries, decompression or asphyxiation in the net. The composition of the discard assemblage is very diverse. It may consist of undersized, immature fish, invertebrates, economically inferior species and in the case of highgrading, even perfectly marketable fish, which are discarded to make room for more valuable catch (Davies et al. 2009; Hill & Wassenberg 2000; Kroese et al. 1995).

Davies et al. (2009) first attempted to define the terms "bycatch" and "discards" in order to simplify quantification of bycatch levels. Davies et al. (2009) state that, so far, bycatch definitions have

concentrated on that part of the catch which is not targeted. Varying perceptions of the value of the catch lead to varying judgments as to what is classified as bycatch and indeed, what is a discard. This is especially true where there is no specific target specie but rather the fishery is a multi-species fishery, as in the case of the South African inshore trawl fisheries.

The definition proposed by Davies et al. (2009) is as follows and will be the definition used in this study:

"Bycatch is catch that is either unused or unmanaged

Where:

- *Unused catch is that which is not used for consumption, sold for any purpose, or reused by the fishers as bait. It includes discards (that portion of the catch that is thrown overboard) and wasted catch after landing that is neither sold nor directly consumed.*
- *Unmanaged refers to catch, whether categorised as individual species or groups of different species, that does not have specific management to ensure the take is sustainable (in keeping with the FAO's Code of Conduct for Responsible Fishing). The effectiveness of any management to ensure the fisher is responsible is a related but separate issue to the current definition of bycatch. To qualify as managed there must be clearly defined measures specifically intended to ensure the sustainable capture of any species or groups of species within any fishing operation."*

Recently there has been increased interest in bycatch and its composition, born out of the sheer amount of fish wasted in the discarding process and the effects that such a large removal of animals will have on the ecosystem (Walmsley et al. 2007a). Although bycatch and discarding have been around since humans have exploited the marine environment, we have only now begun to understand the full scale of it and the implications it may have on fisheries, underestimates of fish mortality and the effect it may have on the environment. Historical information and records on bycatch in particular are scarce, making it hard to gauge the problem in respect to its extent throughout history (Walmsley et al. 2007b).

In South Africa, the awareness of bycatch and discards has evolved during and after the period of transformation in the government following the first democratic elections in 1994. The passing of

the Marine Living Resources Act in 1998 paved the way for a revision of the laws governing the fisheries. One of the key issues addressed in the Act is the need for the sustainable exploitation of South African marine resources (DAFF, 1998). This includes the need to reduce bycatch and discards, especially where bycatch from one fishery may negatively affect another or may endanger one or more species (Attwood & Peterson, 2010; Pascoe, 1997).

Despite this legislation, the South African inshore trawl fishery still catches large amounts of bycatch. Teleosts make up the majority of the bycatch (Walmsley et al. 2007a). Up to 88.7% of the sole-directed catch and 92.6% of hake-directed catch consists of bycatch. Especially hake (*M. capensis*), panga (*Pterogymnus laniarius*) and horse mackerel (*Trachurus capensis*) were found to make up a large proportion of the bycatch (Walmsley et al. 2007a), as these are targeted. Some conflict occurs with other fisheries: in the linefishery, the inshore trawl is accused of capturing and discarding large amounts of juvenile silver kob (*Argyrosomus inodorus*), soupfin shark (*Galeorhinus galeus*), and smoothhound (*Mustelus mustelus*) (Attwood & Peterson, 2010; Walmsley et al. 2007a).

It is important, especially in multi-species fisheries, that catch controls are carefully considered. In the end, quotas on target species only make sense if the bycatch of the fishery is taken into account as well. Because it is virtually impossible to selectively fish only target species, effort must be concentrated on reducing bycatch and discard levels rather than finding and opening markets for bycatch species (Davies et al. 2009). An impediment to bycatch reduction programmes is the lack of adequate catch and abundance data on non-target species.

Although the inshore trawl fishery targets hake and sole, there is a variety of associated bycatch species that are characteristic of a relatively unselective fishery (Walmsley et al. 2007a; Walmsley et al. 2007b). Japp et al. (1994) made the first comprehensive estimation of bycatch and discards for the South African trawl fisheries. However, they state that there are several ways in which the data could have biased the bycatch estimates: 1) commercial trawl gear is more selective than the gear used in surveys; 2) surveys attempt to cover all areas of the benthos, not only grounds that are trawlable; 3) survey trawls are also of shorter trawl track length than commercial trawls; and 4) surveys are conducted mostly seasonally, which may have an effect on specie distribution. Despite these biases, a substantial volume of fish is still discarded (Walmsley et al. 2007a).

Chondrichthyan bycatch

Due to their relatively low commercial value, chondrichthyans have long been ignored in catch statistics and even more so in bycatch statistics. However, due to a resurgence of elasmobranch products and the decline of many chondrichthyan species, new attention has been given to these animals (Stevens et al. 2000; Stobutzki et al. 2002).

Most chondrichthyes possess a life history that will not support long-term consistent exploitation unless carefully managed. Most have both slow growth and reproductive rates. Gestation periods of one year are common, and many species exceed this. The frilled shark (*Chlamydoselachus anguineus*) is estimated to have a gestation period of up to two years (Compagno, 1984a). Some are seasonally migratory or nomadic, meaning they do not fall under any one nation's jurisdiction (Walmsley et al. 2007b).

Therefore, several organisations (such as the IUCN Species Survival Commission Shark Specialist Group and the International Commission for the Conservation of Atlantic Tuna (ICCAT), as well as the Fisheries and Agriculture Organisation of the United Nations) have formed groups or voluntary international management plans that either monitor the progress of conservation or specialise in dealing with chondrichthyes in order to promote the sustainable management of these fish (Kroese et al. 1995; FAO 1999; Fowler et al. 2005). Even so, where reporting is present, some records still lump species into groups, especially where chondrichthyans are not targeted (Stevens et al. 2000). This lack of data hampers efforts to use specie-specific stock assessments to quantify population levels and possible sustainable management (Stobutzki et al. 2002).

South Africa has the highest level of chondrichthyan endemnicity in the whole sub-equatorial Africa region (Kroese et al. 1995). There are 260 species of chondrichthyans in the region, with 79 species being endemic to South Africa (Compagno, 1984b). It is therefore possible that a wide range of chondrichthyan species are caught as bycatch and discarded, but accurate reporting is scarce, and subsequently a protective legislation exists only for some species.

Although a relatively small fishery, chondrichthyans may amount to roughly 10% of the total landing in the inshore trawl fishery (Kroese et al. 1995). It is therefore certain that in excess of 10% of the pre-discard catch would be chondrichthyans. The amount of chondrichthyans commonly caught in the inshore trawl fishery is less than in other fisheries (e.g. Stobutzki et al. 2002). However, for a

relatively small fishery, this still represents a large removal of chondrichthyan biomass from the Agulhas Bank ecosystem.

Most chondrichthyan bycatch is discarded. The only species retained on a permanent basis are the biscuit skate (*Raja straeleni*), the St. Joseph shark (*Callorhinchus capensis*), and the soupfin shark (*Galeorhinus galeus*) (Kroese et al. 1995; personal observation). Other species retained when present are hammerhead (*Sphyrna zygaena*), smoothhound (*Mustelus mustelus*), and bronze whaler (*Carcharhinus brachyurus*) sharks. Most of, if not all the chondrichthyes discards are dead at the time of being thrown overboard.

Some work has been done, for example by Kroese et al. (1995) and Attwood & Peterson (2010), to analyse the composition of the chondrichthyans in the fishery, and highlight dominant species and species of concern:

A large component of the bycatch is the spiny dogfish, *Squalus megalops*. It is estimated that *S. megalops* makes up to approximately 4.5% of the total fish biomass on the Agulhas Bank and it can contribute a high percentage of the catch in some trawls (Kroese et al. 1995).

Concern is also expressed for *Galeorhinus galeus*, as this specie is under fishing pressure from the longline industry as well, where it is targeted and believed that especially pregnant females are taken due to their increased weight (Sauer et al. 2003). In the inshore trawl fishery, it is believed that *G. galeus* can swim fast enough to escape the net, although some animals do get caught. *Galeorhinus galeus* also exhibits the characteristic low fecundity of chondrichthyans, making it prone to depletion.

The St. Joseph shark forms the largest component of the chondrichthyan bycatch. This specie is susceptible to trawling as it feeds on benthic molluscs. It is also a concern that females are utilising the trawling grounds as a breeding ground and that large portions of the female population aggregating there to lay eggs could be caught and removed from the system. There is also a suspicion of highgrading in the case of *C. capensis*.

Batoids, although not targeted, are a regular feature in the catch of the inshore trawl fishery and their bycatch rates are of some concern (Attwood & Peterson, 2010). Compounding this, the biology of the skates and rays of Southern Africa is relatively poorly known (Kroese et al. 1995), although some advancements have been made (Compagno et al. 1991; Ebert et al. 1991; Walmsley-Hart et al. 1999; Watson & Smale 1999). Members of the superorder Batoidea are a typical case where species are lumped to higher taxonomic levels.

Scope of this study

This study will describe trends in the chondrichthyan abundance over the period of time between the commencing of commercial fisheries around 1900 to the present time. It will use data from the original exploratory trawls of Gilchrist (1898 to 1920) and Gilchrist/von Bonde (1930 to 1948), and compare these to data from the modern surveys. Although the survey methods are not directly comparable, statistical methods will be employed to reduce the effects of variation in gear efficiency and survey designs, to provide robust estimates of changes in specie composition and abundance. Changes in specie composition and abundance could be caused directly by exploitation, environmental factors or a combination of these. Teasing these causes apart might be aided by clear predictions on the effect of exploitation, i.e. certain types of species are expected to diminish. In contrast, climate change effects are less predictable, with increases and decreases being equally possible. This work will not provide stock assessments, but it will provide an empirical indication of which species in the total bycatch assemblage are most at risk.

Layout

1. Chapter 2 is an investigation into the long-term changes in trawl catch composition on the inshore Agulhas Bank: changes over time and between areas will be investigated, with particular emphasis on chondrichthyans.

2. Chapter 3 is an investigation into changes in the abundance of chondrichthyan species on the Agulhas Bank, using a swept area index of density.

3. Chapter 4 is a concluding chapter, which comments on the vulnerability of chondrichthyans in the light of the empirical evidence presented, and evidence of similar studies elsewhere.

4. Bibliography

5. Appendix containing species lists showing the lumping within higher taxonomic levels used in this analysis

CHAPTER 2: LONG TERM CHANGES IN TRAWL CATCH COMPOSITION ON THE INSHORE AGULHAS BANK, WITH EMPHASIS ON CHONDRICHTHYAN BYCATCH SPECIES

Abstract

This study tests the hypothesis that the relative chondrichthyan catch composition of five surveys spanning the period of 1898 to 2010 has remained unchanged over the course of over 100 years of industrial fishing pressure by bottom trawlers. Five data sets were used in a comparison over space and time. These were the first and second Gilchrist surveys (1898 to 1920 and 1930 to 1933), the small mesh survey conducted by Wallace et al. (1984), the observer programme database (2002 to 2006) and the annual South Coast trawl survey (1985 to 2010). Analyses were conducted at three taxonomic levels across three historically important trawl grounds. Selected stations were analysed using the multivariate techniques to visualise broad trends. Analysis of Similarities (ANOSIM) was used to test the significance of any trends, Similarity Percentages (SIMPER) to examine which species caused the dissimilarity among sample groups and mixed-model Permutational Manova (PERMANOVA) statistics were used to quantify the contribution of area on dissimilarity among the samples over time. Significant declines were reflected in the chondrichthyan groups Squalidae, Rhinobatidae, Torpedinidae and Narkidae. Increases were found in the relative abundance of *Callorhinchus capensis* and the teleosts horse mackerel (*Trachurus capensis*), hake (*Merluccius spp*), and gurnards (*Chelidonichthyes spp*). There were significant differences among the three trawl grounds and among 5 by 5 minute grid blocks within these grounds. With the exception of *Callorhinchus capensis*, the trends largely reflect trends found in other temperate bottom trawl fisheries.

Introduction

It is common practice to use fisheries survey data and catch records from the latter half of the past century to assess fisheries and specifically the degree of stock depletion (ICES, 2010; Martell & Walters, 2004). Most of these industrial fisheries commenced fishing prior to the year 1900, with the advent of steam driven boats. Assessment models based on recent data typically estimate initial conditions in the fishery by model fitting (e.g. Rademeyer et al. 2008). It is much rarer to find examples where historical fisheries data from the beginning of industrial-scale fishing have been used in contemporary assessments. Usually, such historical data are either unavailable, of poor quality or are deemed not to represent conditions of modern gear, efficiency and fishing behaviour. Where such appropriate historical data are available, such information may provide a powerful addition to assessment procedures, provided that changes in technology and fishing behaviour can be accounted for.

A more common usage of historical data has been the description of changes in specie composition rather than qualitative assessments of target specie strength (McHugh et al. 2011). The ability to detect broad-scale changes in fish communities is less dependent on the accurate determination of catchability factors. The need to assess bycatch species is a rather recent development and the necessary time-series data for such an assessment are generally representative of only the most recent period of commercial fisheries. Historical survey and fisheries catch statistics may be useful in assessing the impacts of fishing at an ecosystem level. This is provided that they reflect the entire spectrum of the catch, as an Ecosystem Approach to Fisheries (EAF) requires that the fishery should be managed with respect to all species impacted by it, and not only those being targeted (Garcia & Cochrane, 2005).

Chondrichthyans are among the species most likely to be impacted by non-specific gear as they have low reproductive and growth rates and are thus easily impacted by only a few years of fishing effort (Stevens et al. 2000). In South Africa, fisheries assessments on chondrichthyans have been limited to only one specie (the soupfin shark, *Galeorhinus galeus*) despite the prevalence of this class of fishes in South Africa's commercial catches.

Jukic-Peladic et al. (2001) looked at the trends of osteichthyan and chondrichthyan species of fisheries importance in the Adriatic Sea. The data collected in a survey conducted in 1998 was compared to surveys conducted in 1948. They concluded that the greatest change was in levels of

elasmobranch diversity and frequency in catches, especially among the Batoidea. The authors concluded that fishing pressure was the cause of the declines as the reproductive strategies of these species could not sustain the high fishing effort directed at the more productive teleost targets.

Older trawl survey data were examined by (McHugh et al. 2011) dating back from 1913 to 1922 in the Western English Channel. When compared to recent survey data, the authors found considerable changes in the elasmobranch portion of the catch, especially the skates (Rajidae), and the angle shark (*Squatina squatina*), to the extent that it indicated extirpation.

Fishing affects the overall diversity and evenness of the community it impacts (Jennings et al. 2006). Yemane et al. (2010) looked at the trends of diversity over the course of over twenty years of scientific survey trawling on the Agulhas Bank in South Africa and found a significant increase in diversity and a significant decrease in dominance. It is therefore not always correct to assume that fishing reduces diversity and that the action of trawling may alter the ecosystem in such a manner that competitive hierarchies are altered, potentially favouring species that are normally less dominant. Potential weakness in their study stems from their relatively short time series, and that long term changes may have been missed.

In this chapter, I will examine the long-term trends in the catches of the inshore trawl on the Agulhas Bank by comparing survey data collected in the periods 1898 to 1904, 1922 to 1948, 1980, and 1985 to 2010. The usefulness of such a comparison is based on the premise that the earliest of these surveys reflect baseline conditions for the Agulhas Bank. Trawling is the only form of fish exploitation on the unconsolidated sediments of the Agulhas Bank. Linefisheries are spatially disjunct to the trawl grounds, being concentrated on rocky bottom.

These datasets will be used to test whether there have been consistent changes in chondrichthyan specie assemblage composition on the Agulhas Bank, with respect to the individual species and the overall catch composition. This analysis will be the first attempt at empirically evaluating the effects of South Africa's oldest industrial scale fishery.

Methods

Research approach

The approach used in this study is to compare the catch composition of trawlers on the inshore Agulhas Bank among five surveys conducted over the period from 1898 to 2010. The overall hypothesis being tested is that the catch composition of chondrichthyans has remained unaltered over the course of the 100 plus years of exploitation by trawlers. This hypothesis was phrased more specifically with respect to taxonomic resolution as described below under the statistical methods. Although the spatial extent of the surveys did not overlap exactly there was sufficient overlap to conduct comparisons on an area by area basis, thereby removing the effect of geography as far as possible.

Data sources

Survey data 1898 to 1904

The first ship-based marine biological surveys involved the use of trawls between Walvis Bay, Namibia and Maputo, Mozambique. These surveys were concentrated near metropolitan areas for the purpose of documenting fish availability near markets. Survey catch records are remarkably complete, including fish and invertebrates. The data can be found in list form in Gilchrist (1899; 1900; 1901; 1902; 1903; 1904) and on the SAEON website. All trawls were done from the vessel *FRV Pieter Faure*, a purpose-built, steam driven survey vessel. The trawl net was estimated to be 12 m across and had a mesh size of 75 mm.

The start and end position of each trawl was recorded by angular reference (compass bearing) and distance to a prominent feature on land. These feature were located on a chart and the references were converted to geographical coordinates (WGS 1984) using cartographic techniques.

Survey data 1922 to 1948

After a hiatus caused by World War One, government trawls resumed in 1922 using the *SS Pickle* (Gilchrist & Von Bonde, 1923a) and the *FRV Africana* (Von Bonde, 1933a), both steam driven vessels. The size of the survey trawl net increased to 40 m, but the mesh size remained at 75 mm. The position of trawls was determined by sextant and radio positioning. The data can be found in list and tabular form in Gilchrist & Von Bonde (1923, 1924, 1925, 1926, 1927, 1929a, 1929b, 1930) and Von Bonde (1932, 1933a, 1933b, 1934, 1935, 1936, 1937, 1938, 1939, 1940, 1941, 1942, 1943, 1944, 1945, 1946, 1947, 1948, 1949, 1950). Start positions, a bearing and the trawl distance were recorded.

Small mesh survey 1980

Surveys of shallow trawl grounds between Mossel Bay and Algoa Bay were undertaken using the *TB Davie* and a small mesh net in 1980. Although the otter trawl nets had a stretch mesh of 50 mm and 70 mm, the cod end was lined with 12 mm knotless netting. Surveys were concentrated between the depths of 4.5 m and 50 m. The voyages of the *TB Davie* covered the following months: February, May, August and November (Wallace et al. 1984). Start and end positions for each trawl were recorded for this survey as well.

Observer data 2003 to 2006

The second offshore resources observer programme was operated from September 2002 to October 2006. Observers were randomly stationed on commercial hake and sole directed trawlers. They recorded, among other things, the pre-discard catch in the trawl net. Each catch was sub-sampled and the mass and number of each specie in the sample was recorded and extrapolated to estimate the total haul. Attwood, Peterson and Kerwath (2011) described the sampling procedure in detail. The entire trawl ground was sampled out to a depth of 110 m. Start and end positions for each trawl were recorded. The trawl nets were either 75 mm stretch mesh (sole-directed or 90 mm stretch mesh (hake-directed).

Contemporary trawl surveys

The South Coast trawl surveys were conducted by DAFF (Department of Agriculture, Forestry and Fisheries) from 1985 until the present. This is a survey of randomly selected grid blocks conducted off the South Coast on the Agulhas Bank twice a year, in spring and autumn. The nets used for the surveys have a cod-end of 75 mm stretch mesh and a 35 mm net liner. All species and positions were recorded and trawl times were 30 minutes (Yemane et al. 2010).

Study areas

The inshore trawl area is the area of the Agulhas Bank between Cape Agulhas (20° east) in the west and East London (24° east) in the east. It covers the majority of the width of the Agulhas Bank; from the widest point off Cape Agulhas to the narrow shelf margin off Algoa Bay and eastwards. Trawling is concentrated on specific grounds within this area and three specific grounds have been consistently targeted over the years. These grounds are off Cape Infanta, Mossel Bay and Algoa Bay. Inshore trawlers select their grounds depending on whether hake or sole is the target, hake becoming progressively more important over the course of the 20th century as refrigeration and ships' power improved.

For the purpose of finding areas representative in each of the surveys, a 5 by 5 minute trawl grid was superimposed over the entire South African Exclusive Economic Zone. Each trawl was assigned to a grid block, using the midpoint of each trawl. Comparisons were made among surveys using commonly trawled grid blocks. For this purpose grid blocks were only selected if a minimum of three trawls from each survey were represented. However, emphasis was placed on the most historical and the most recent datasets. There would have been insufficient grid representation of each survey at a finer grid resolution. Selected grids can be seen in Figure 2.

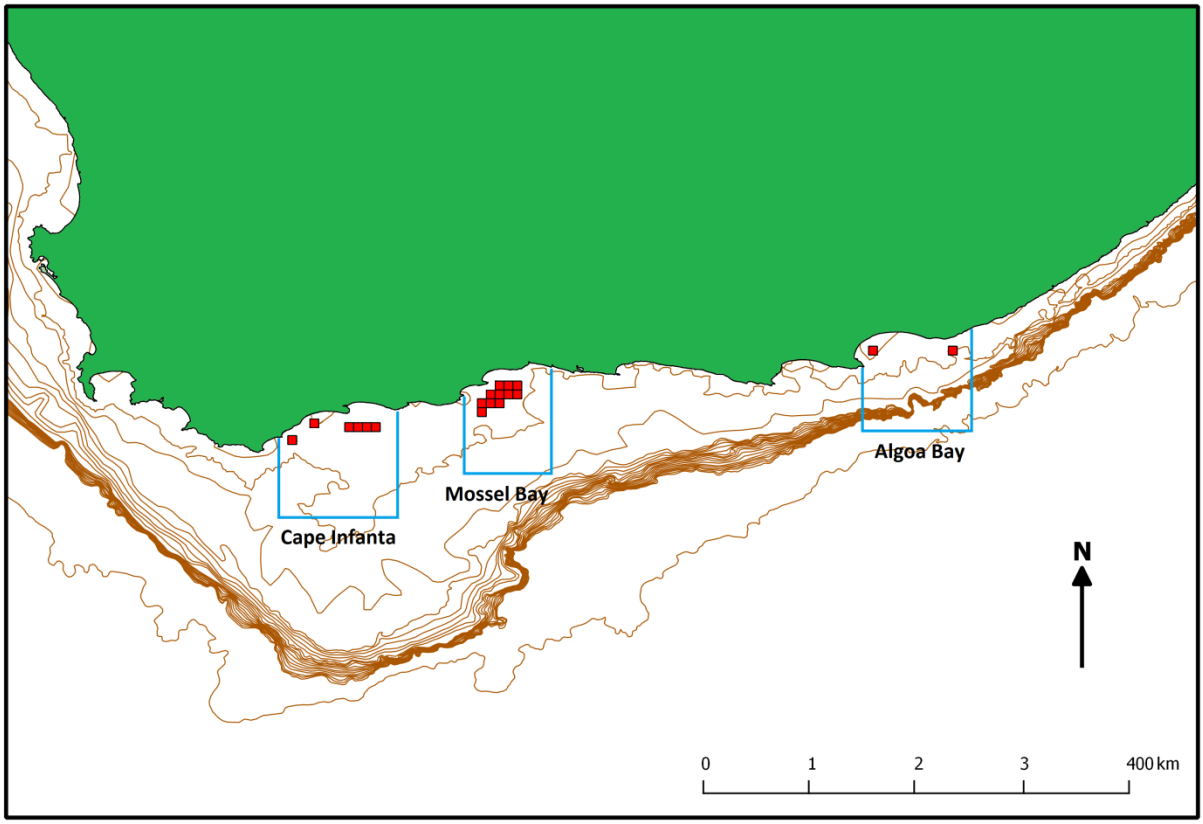


Figure 2: Final selection of trawl grids in the inshore zone off the south coast of South Africa. Only grids containing a minimum of three trawls per survey were chosen. Trawl grounds are represented by labelled blocks.

Statistical methods

The overall hypothesis was framed in several ways to examine the effect of variable taxonomic and temporal resolution.

Null hypothesis 1: The catch composition by order did not differ among the surveys nor trawl grounds. Abundances were aggregated at the order level for the most robust analysis of change in catch composition.

Null hypothesis 2: The catch composition by family did not differ among the surveys nor trawl grounds. For this analysis abundances were aggregated at the family level to overcome taxonomic uncertainty.

Null hypothesis 3: The specie composition in the trawl catches did not differ among the surveys or the trawl grounds. It was not possible to separate the catch to specie level in every case, as the early datasets used different classification schemes to what is currently accepted. Whereas the vast majority of fish could be identified at the specie level, those that could not were assigned to genus, family or order level (Appendix 1).

The same procedure was used for testing each hypothesis, as set out below. The following small pelagic species were excluded from the data as they had no relevance to the benthic fish community structure and their large and often erratic appearance in catches led to unnecessary variance: *Engraulis capensis*, *Sardinops sagax* and *Etrumeus spp*. Catch data were standardised to eliminate the effect of varying catch rates and gear efficiency among surveys by converting each specie contribution by number in each trawl to a value expressed as a percentage of the total catch in that trawl. Data were then root-root (fourth root) transformed to reduce the influence of the dominant species. A Bray-Curtis similarity matrix was created using the group average linkage. This measures the similarity between every pair of samples using the relative abundance of species in the paired samples. The triangular Bray-Curtis coefficient table was then displayed visually by way of dendrograms and multidimensional scaling plots (MDS). One way Analysis of Similarity (ANOSIM) tests were conducted to discriminate differences within and among surveys and trawl grounds. This compared the similarity among samples within individual surveys and trawl grounds and the dissimilarity among the surveys and trawl grounds themselves. ANOSIM is a non-parametric analysis of variance based on the ranked similarity between samples in the Euclidean space underlying the Bray-Curtis similarity matrix. The test results in a global R-statistic testing the null hypothesis that there is no difference between surveys or trawl grounds.

To increase the power of tests between widely divergent periods, the two historic surveys were lumped together (Group I) and the two most recent surveys were lumped together (Group II) under a factor called *Period*. Because the Small Mesh Survey consistently formed an outlier (possibly due to the difference in mesh size), this dataset was excluded from further analysis. Hypotheses 1 to 3 were re-phrased to test for differences between periods and trawl grounds. The same statistical procedures were used as above but with the addition of a mixed-model Permutational Multivariate ANOVA (PERMANOVA), which simultaneously tested the effect of *Period*, *TrawlGround* and *GridBlock* by random permutations of the data in an ANOVA environment. By analysing the interaction of the three factors, it was hoped that underlying changes in especially the spatial environment (macro- and micro scale) could be discerned from any overlying temporal trends. The main difference between the ANOSIM and the PERMANOVA tests is that ANOSIM looks at the

ranked difference between samples, whereas PERMANOVA looks at the similarity values themselves. The resulting pseudo-F and pseudo-t values are comparable to the ANOVA F-statistic, with the difference of the pseudo-F being derived from permutations of the samples. The factors *Period* and *TrawlGround* were fixed, whereas *GridBlock* was a random effect, nested in *TrawlGround*. This meant that grid blocks were tested against each other within trawl grounds. *Period* was crossed with *TrawlGround*. Model estimates were derived from 9999 permutations.

Similarity Percentages (SIMPER) analysis was run using the periods and areas as factors in separate analyses, to identify taxa that characterise each period or trawl ground, and those that differentiated the surveys or trawl grounds.

All multivariate statistics were preformed in PRIMER 6 with the PERMANOVA add-on package (Clarke & Gorley, 2006; Clarke & Warwick, 2001; Anderson et al. 2008).

Throughout this chapter, the following abbreviations are used to label the surveys:

GI= First Gilchrist Survey, 1898 to1904

GII= Second Gilchrist Survey, 1922 to 1933

WSM= Wallace Small Mesh Survey, 1980

SCTS= Department of Agriculture, Forestry and Fisheries South Coast Trawl Survey, 1985 to 2010

OD= Observer Programme Database, 2002 to 2006.

Results

Sample sizes

Although trawls were spread across a wide range of grid blocks, only a few grid blocks had trawls that were representative of each period. The analyses that follow are based on 777 trawls, distributed over the five surveys, which fall into common grid blocks (Table 1). The number of trawls per survey varied widely, but the combined number per lumped period was roughly equivalent. There were 369 trawls in the first two surveys (prior to 1933) and 408 trawls in the last three

surveys. The Mossel Bay area was the most well represented with 11 grid blocks that had three or more trawls per period as opposed to Algoa Bay, which had only 2 and Cape Infanta which had 6 (refer to Table 1).

Table 1: Trawls per grid block and trawl ground and total trawls per grid block and trawl ground listed by survey. Grand total values listed are before the removal of trawl outliers during the analysis process. GI= First Gilchrist Survey, GII= Second Gilchrist Survey, WSM= Wallace Small Mesh Survey, OD= Observer Database, SCTS= South Coast Trawl Survey. CI= Cape Intanta, MB= Mossel Bay, AB= Algoa Bay.

Trawl Ground	Trawl Grid	Survey					Grand Total
		GI	GII	WSM	OD	SCTS	
CI	5590		4			13	17
	5767		8		28	1	37
	5901	20				19	39
	5947	68				8	76
	5993	44				11	55
	6038	9				14	23
CI Total		141	12		28	66	247
MB	6566	8			1	7	16
	6567	23			22	6	51
	6610	19			17	9	45
	6611	26	2		13	5	46
	6655	14			4	9	27
	6656	31			4	7	42
	6657	5		12	46	17	80
	6701	48			5	10	63
	6702	5			32	12	49
	6746	6				6	12
	6747	10			43	5	58
MB Total		195	2	12	187	93	489
AB	8519	5				10	15
	8922	14				12	26
AB Total		19				22	41
Grand Total		355	14	12	215	181	777

Specie composition

The Mossel Bay grounds had the greatest diversity at order and family level, and among the surveys the South Coast Trawl Survey was the most diverse (Table 2). Twenty-three orders, 52 families and 83 species were found in the common grid blocks analysed. Chondrichthyans that are present in the trawls belong to 7 orders, 13 families and 23 species (PRIMER).

Four chondrichthyan families were represented across all surveys. These were Rajidae, Rhinobatidae, Squalidae and Torpedinidae (Table 3). Commonly reported families were Carcharhinidae, Dasyatidae, Sphyrnidae and Callorhinchidae, whereas Scyliorhinidae, Narkidae and Pristiophoridae were less frequently represented. The South Coast Trawl Survey had the highest number of families represented, whereas the First Gilchrist Survey and the Observer Database had the least. The observer data are derived from sub-samples of trawls, which may explain the lower diversity in that survey.

Table 2: The total number of trawls in each survey on each trawl ground. The total number of orders, families and species present on the trawl grounds also are given, including the number of chondrichthyan orders, families and species (presented in brackets). Catch per Unit Effort (Number of Fish per Hour) was averaged across all stations of a survey on the individual trawl grounds. Surveys are abbreviated as follows: GI= First Gilchrist Survey; GII= Second Gilchrist Survey; WSM= Wallace Small Mesh Survey; OD= Observer Database; SCTS= South Coast Trawl Survey.

Survey		Cape Infanta	Mossel Bay	Algoa Bay
GI	Trawls	141	195	19
	Orders	12 (4)	16 (6)	12 (4)
	Families	18 (5)	29 (8)	19 (5)
	Species	23 (5)	38 (8)	27 (5)
	Average CPUE	59.0	27.0	32.3
	Number of Gridblocks in common set	4	11	2
GII	Trawls	12	2	0
	Orders	12 (5)	5 (0)	
	Families	21 (8)	7 (0)	
	species	27 (9)	12 (0)	
	Average CPUE	43.3	24.8	
	Number of Gridblocks in common set	2	1	
WSM	Trawls	0	12	0
	orders		13 (6)	
	families		25 (10)	
	species		31 (12)	
	Average CPUE		22.5	
	Number of Gridblocks in common set		1	
OD	Trawls	28	187	0
	orders	11 (4)	14 (5)	
	families	14 (4)	30 (10)	
	species	43 (11)	41 (15)	
	Average CPUE	57.9	81.1	
	Number of Gridblocks in common set	1	10	
SCTS	Trawls	66	93	22
	orders	15 (5)	18 (6)	15 (7)
	families	31 (8)	30 (9)	30 (11)
	species	36 (9)	41 (13)	37 (12)
	Average CPUE	158.6	151.0	139.0
	Number of Gridblocks in common set	6	11	2

Table 3: Presence/Absence of chondrichthyan families per survey. Presence in the selected trawls is indicated by "1". "0" indicates presence in the survey, yet absence from the selected trawls, whereas a blank value field indicates that the family was not recorded at all in that survey. The south coast trawl survey had the greatest chondrichthyan diversity, due to the sampling of both trawl grounds, trawlable grounds (outside of the existing trawl grounds) and the sampling of deeper water. The historical trawls and the observer database, using the same mesh size, are equally selective toward chondrichthyans in the trawls analysed. GI= First Gilchrist Survey, GII= Second Gilchrist Survey, WSM= Wallace Small Mesh Survey, OD= Observer Database, SCTS= South Coast Trawl Survey.

Order	Family	GI	GII	WSM	OD	SCTS
Carcharhiniformes	Carcharhinidae	0	1	1	1	1
	Scyliorhinidae	0	1	0	1	1
	Sphyrnidae	1	0	1	0	1
Chimaeriformes	Callorhinchidae	1	0	1	1	1
	Chimaeridae		0		0	0
Hexanchiformes	Hexanchidae				0	0
Lamniformes	Alopiidae		0		0	0
Myliobatiformes	Dasyatidae	1	1	1	0	1
	Gymnuridae	0	0	0	0	1
	Myliobatidae	0	1	1	1	1
Pristiformes	Pristidae		0		0	
Pristiophoriformes	Pristiophoridae	0	0	0	0	1
Rajiformes	Rajidae	1	1	1	1	1
	Rhinobatidae	1	1	1	1	1
Squaliformes	Squalidae	1	1	1	1	1
Squatiniformes	Squatinidae		0			0
Torpediniformes	Narkidae	1	0	1	0	1
	Torpedinidae	1	1	1	1	1
Total		8	8	10	8	13

Comparison of order composition among surveys and trawl grounds

At this most coarse comparison the surveys clustered separately, with a continuum from the first survey to the last two surveys (Figure 3). Very few trawls were available from the Second Gilchrist Survey for comparison. Although the two most contemporary surveys failed to separate clearly, the observer data was considerably more heterogeneous than the South Coast Trawl Surveys. Ignoring geographical influences, ANOSIM revealed that there was a significant dissimilarity among surveys ($R=0.679$, $p=0.001$).

Similarity in species composition within surveys was highest in the First Gilchrist Survey (73.42% similarity), followed by the Observer Database (67.06% similarity) and the Second Gilchrist Survey (66.83% similarity). Among the remaining recent datasets, the highest similarity was found within the Small Mesh Survey (62.36% similarity) and the South Coast Trawl Survey (47.08% similarity). Thus, similarity within the individual surveys decreases with time. The observer database, due to the nature of targeting, has a comparable similarity to the historical surveys.

Dissimilarity in species composition among surveys was caused mainly by teleosts. Among chondrichthyans the First Gilchrist Survey was dominated by Rajiformes, Torpediniformes and Squaliformes. The Second Gilchrist Survey had comparatively fewer chondrichthyans, as did the South Coast Trawl Survey, but the Wallace Small Mesh survey contained an abundance of Myliobatiformes, Chimaeriformes, Carcharhinifomes, Squaliformes and Rajiformes. The observer data were relatively rich in Rajiformes and Chimaeriformes.

Relative to the two latest surveys, the First Gilchrist Survey was characterised by relatively more Torpediniformes, Rajiformes, Squaliformes and Myliobatiformes whereas the latter were richer in Carcharhiniformes and Chimaeriformes.

In contrast to the temporal differences, when the data were separated by the spatial distribution of the *TrawlGround* factor only, the Bray-Curtis dissimilarity in order composition was not significant as assessed by ANOSIM (Global $R=0.018$, $p=0.085$).

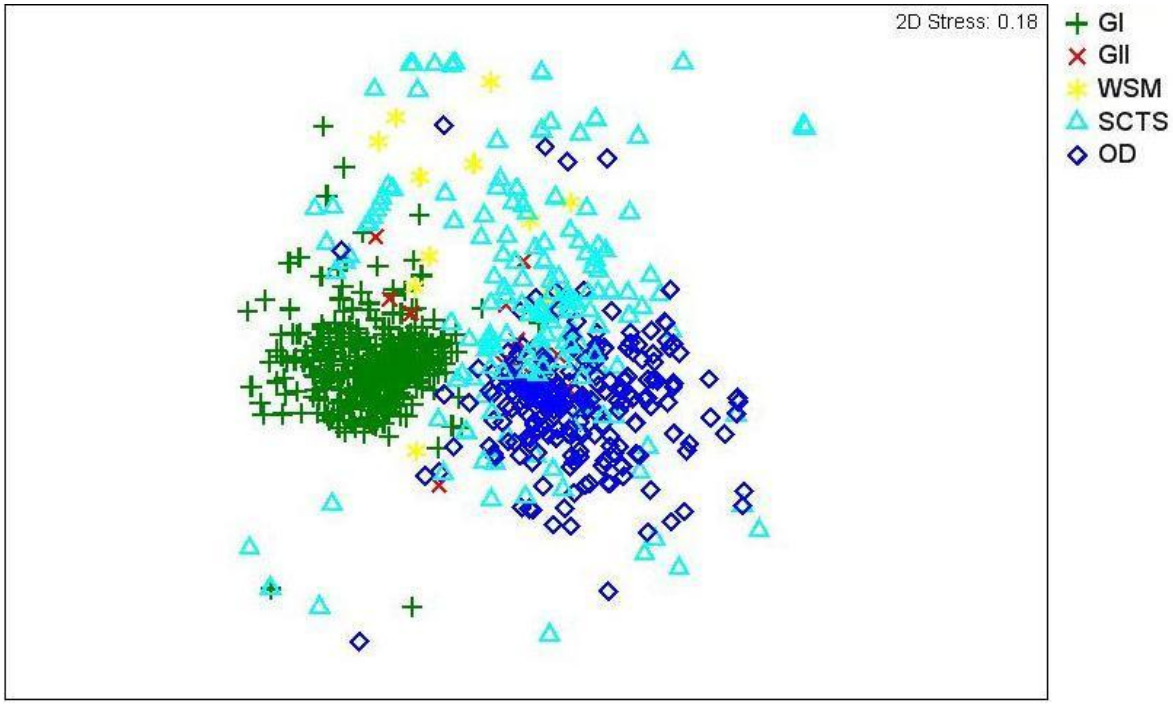


Figure 3: Multi-dimensional Scaling plot showing similarity among trawls from different surveys spanning 110 years of trawling activity. The ordination is based on order composition. Continuum of the surveys from historical to recent (left to right) is visible. Data is based on Bray-Curtis dissimilarity and shown following standardisation and root-root transformation. GI= First Gilchrist Survey (1898-1904); GII= Second Gilchrist Survey (1922-1933); WSM=Wallace Small Mesh survey (Wallace et al. 1984); SCTS=DAFF South Coast Trawl Survey (1985-2010); OD=Observer Database (2002-2006).

All trawl grounds had the Rajiformes as a common dominating order among chondrichthyans. The Cape Infanta catches also contained the Torpediniformes within the top 95% in the catch (Figure 4). The percentage dissimilarity among all combinations of grounds was approximately 50%, despite the east-west distribution, and shows that the two grounds at the extremes have elements in common, not shared by the central Mossel Bay ground.

Relative to Cape Infanta, Mossel Bay samples had more Rajiformes, Squaliformes and Chimaeriformes, but less Torpediniformes. Relative to Mossel Bay, Algoa Bay had Squaliformes and Myliobatiformes, but less Rajiformes, Torpediniformes and Chimaeriformes. Cape Infanta had more Rajiformes and Torpediniformes, but less Squaliformes and Myliobatiformes relative to Algoa Bay (Figure 5).

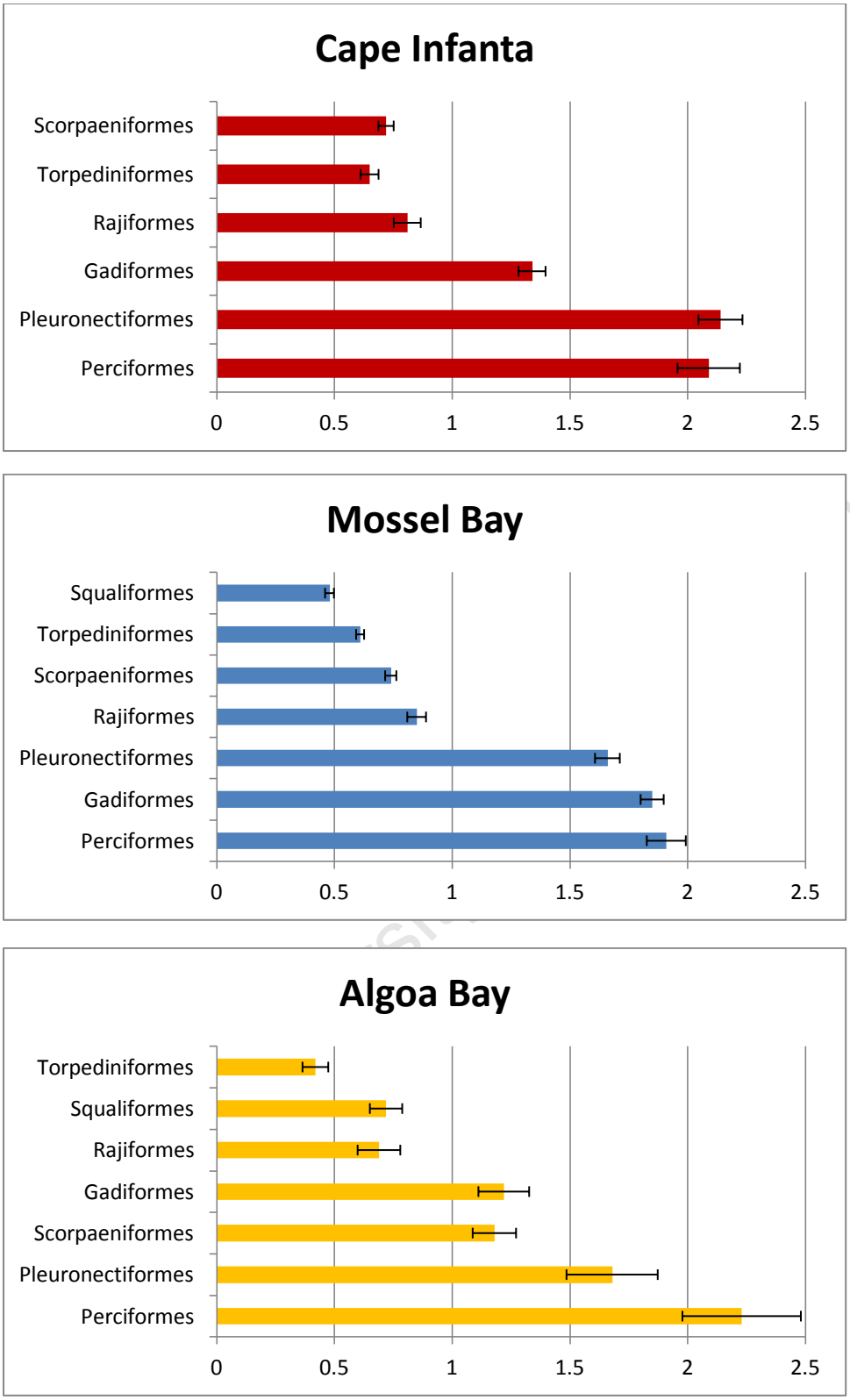
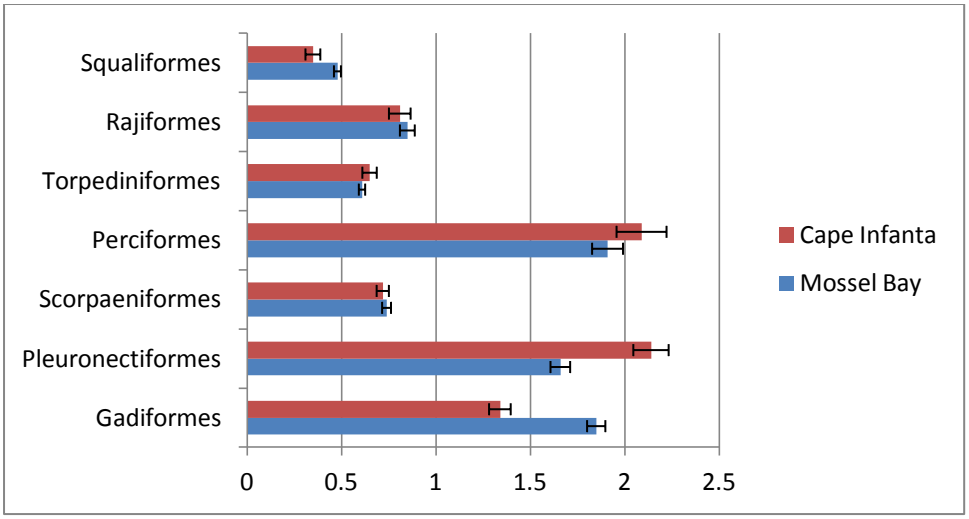
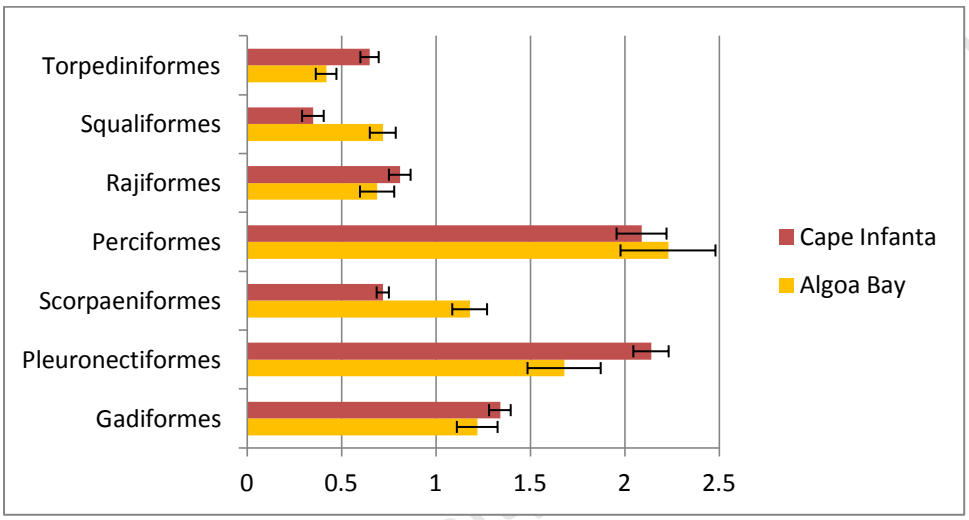


Figure 4: The results of a SIMPER analysis showing average relative abundance (standard error given in parentheses) at order level within trawl grounds. Only orders that contribute 95% to the similarity within a site are displayed. Average similarity was 50.95% on the Algoa Bay ground, 59.77% on the Cape Infanta ground and 52.81% on the Mossel Bay ground.





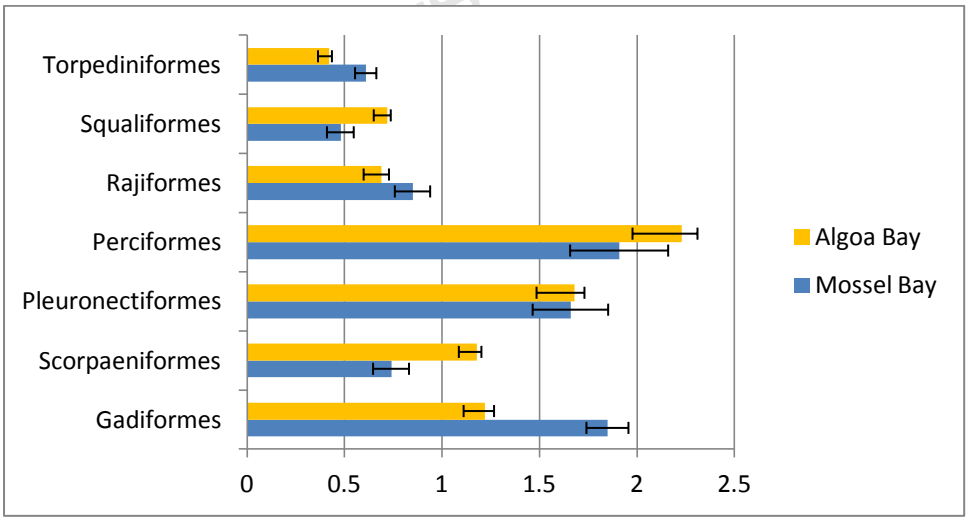


Figure 5: The results of a SIMPER analysis showing average relative abundance (standard error given in parentheses) at order level among trawl grounds. Only orders that contribute 95% to the dissimilarity among sites are displayed. Average dissimilarity were as follows: Cape Infanta/Mossel Bay: 46.04%; Mossel Bay/Algoa Bay: 50.83% and Cape Infanta/Algoa Bay: 47.09%.

Comparison of family composition among surveys and trawl grounds

Dissimilarities among surveys at the family level follow a remarkably similar pattern to the one found in the order level analysis, with a continuum from the earliest to the latest surveys (Figure 6). Again the South Coast Trawl Survey was the least similar, and the First Gilchrist survey the most similar. The least similarity was between the Wallace Small Mesh Survey and all other surveys. The differences among surveys were significant (R=0.731, p=0.001).

Among surveys, the Gilchrist surveys had more Rajidae, Narkidae, Squalidae, and Torpedinidae than the South Coast Trawl Survey, although the Second Gilchrist Survey lacked the Narkidae and instead had the Myliobatidae and Carcharhinidae. Between the First Gilchrist Survey and the Observer Data, there were relatively more of the Callorhinchidae, whereas the Rajidae, Narkidae, Squalidae and Torpedinidae were relatively less. A similar pattern is followed between the Second Gilchrist Survey and the Observer Data, with Callorhinchidae having a relatively greater proportion, but the Rajidae, Torpedinidae, Squalidae, Myliobatidae and Carcharhinidae being relatively less.

In comparison to the order level analysis, ANOSIM showed that the difference among grounds on the basis of family composition were significant (R=0.03, p=0.0015). The splitting of the Perciformes in to the Carangidae and the Sparidae, as well as the splitting of the Pleuronectiformes into the Soleidae and the Cynoglossidae had the greatest influence on the pattern relative to the order-level analysis. The families belonging to the Perciformes and the Pleuronectiformes were not as dominant as these orders were in the previous analysis. With respect to cartilaginous fishes, the orders that were important were represented mostly by one family, in each case, thereby leading to a similar result at the family level.

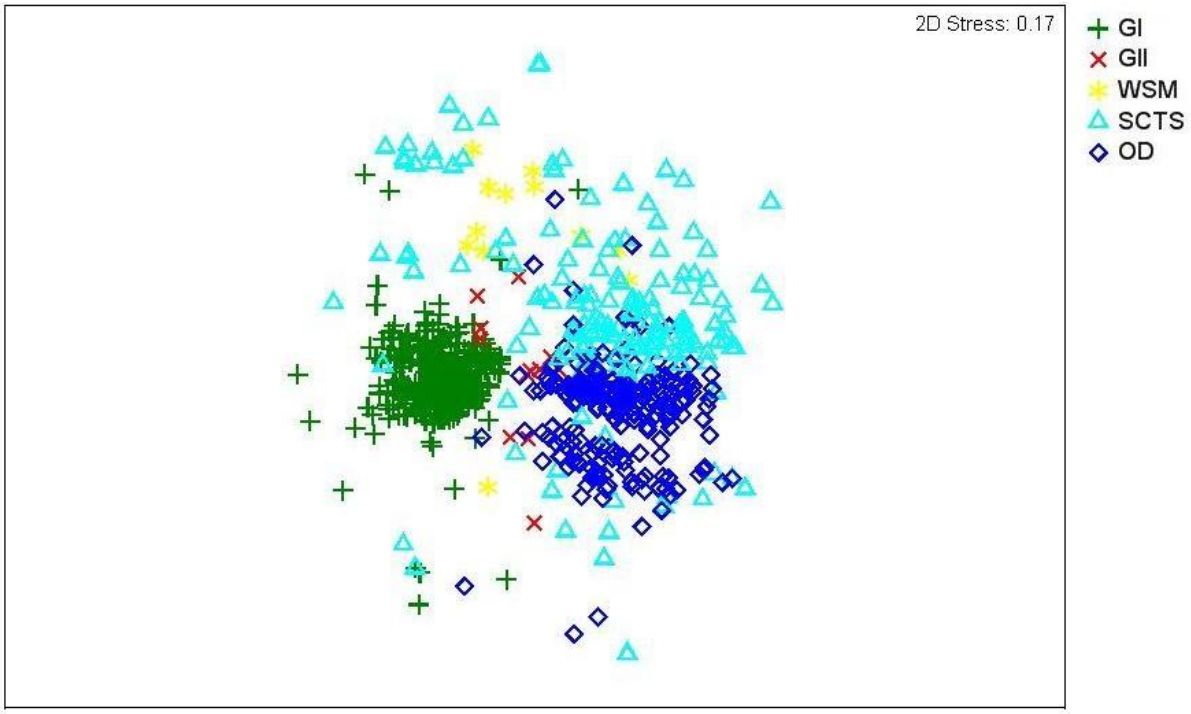


Figure 6: Multi-dimensional Scaling plot showing similarity among trawls from different surveys spanning 110 years of trawling activity. The ordination is based on family composition. Continuum of the surveys from historical to recent (left to right) is visible. Data is shown following standardisation and root-root transformation and based on Bray-Curtis dissimilarity. GI= First Gilchrist Survey (1898-1904); GII= Second Gilchrist Survey (1922-1933); WSM=Wallace Small Mesh survey (Wallace et al. 1984); SCTS=DAFF South Coast Trawl Survey (1985-2010); OD=Observer Database (2002-2006).

All trawl grounds had 6 families in common. In addition, Mossel Bay and Algoa Bay had 7 families in common, and Algoa Bay had the most number of families, with 1 family unique to that area (Cynoglossidae) (Figure 7). The family level analysis gave different quantitative results to the order level analysis (Figure 8): Mossel Bay and Algoa Bay were least similar (59.58% dissimilarity), Algoa Bay and Cape Infanta were most similar (56.04% dissimilarity), despite being furthest apart geographically, and Cape Infanta and Mossel Bay gave a mid-range similarity (56.54% dissimilarity).

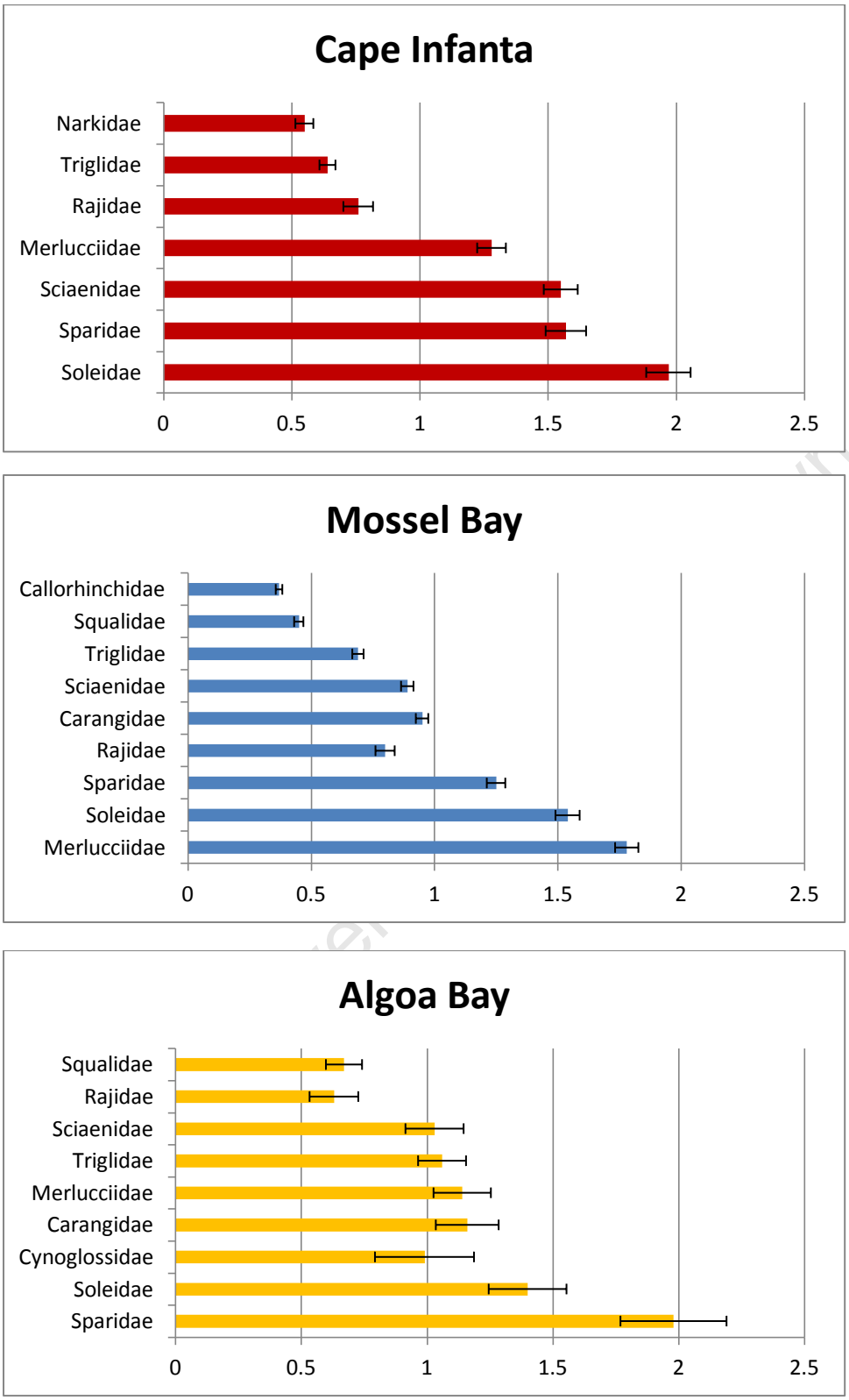


Figure 7: The results of a SIMPER analysis showing average relative abundance (standard error given in parentheses) at family level within trawl grounds. Only families that contribute 95% to the similarity within a site are displayed. Average similarity was 46.86% on the Algoa Bay ground, 52.29% on the Cape Infanta and 42.77% on the Mossel Bay ground.

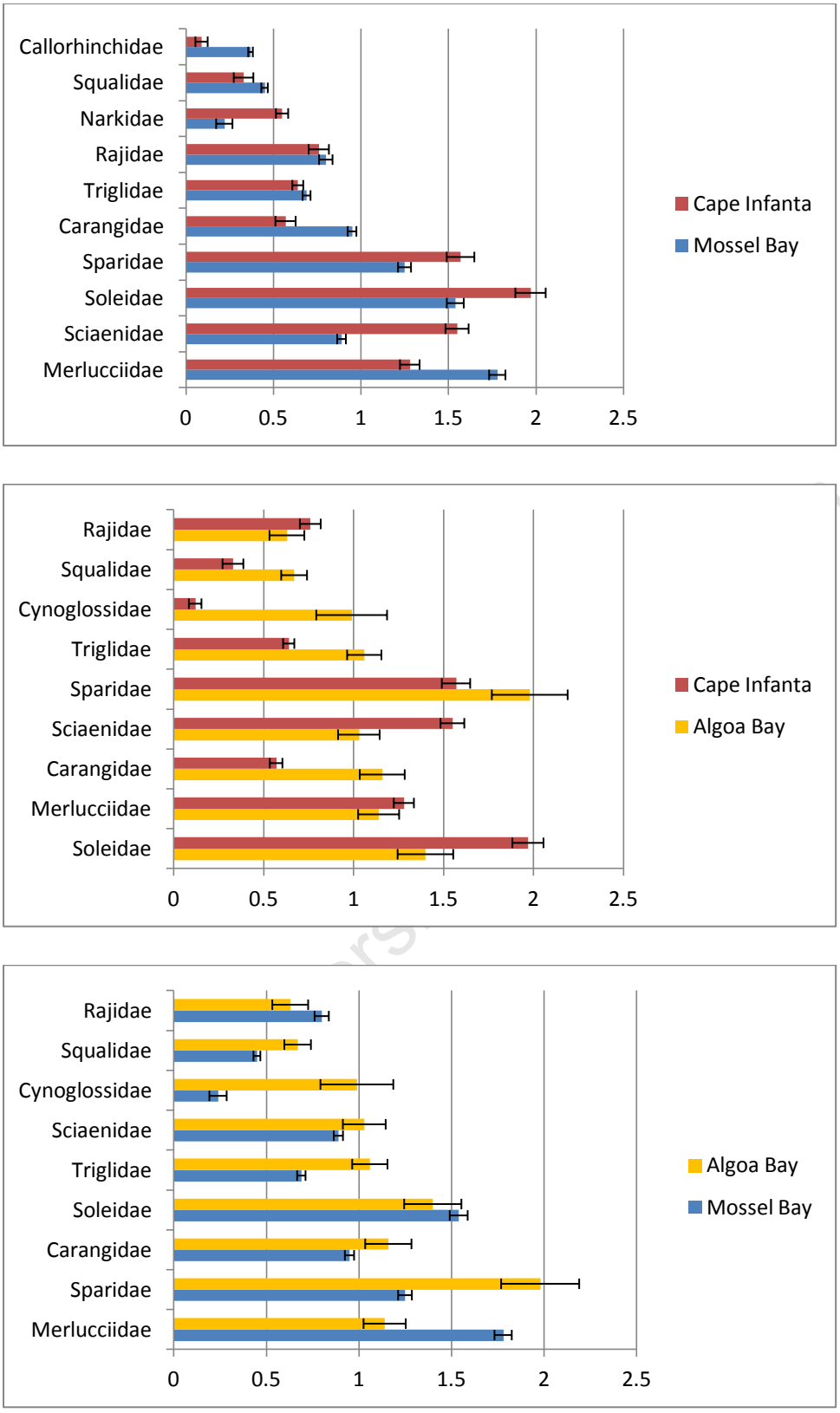


Figure 8: The results of a SIMPER analysis showing average relative abundance (standard error given in parentheses) at family level among trawl grounds. Only families that contribute 95% to the dissimilarity among sites are displayed. Average dissimilarities are as follows: Cape Infanta/Mossel Bay56.54%; Mossel Bay/Algoa Bay: 59.58% and Cape Infanta/Algoa Bay: 56.04%.

Comparison of specie composition among surveys and trawl grounds

The MDS plot of surveys follows a similar continuum as seen with the order and family level analysis (Figure 9). A significant difference was found among the surveys (R=0.745, p=0.001). Large contributions to dissimilarity were found to stem from the presence or absence of *Raja spp*, *Narke capensis* and *Squalus spp.* among surveys.

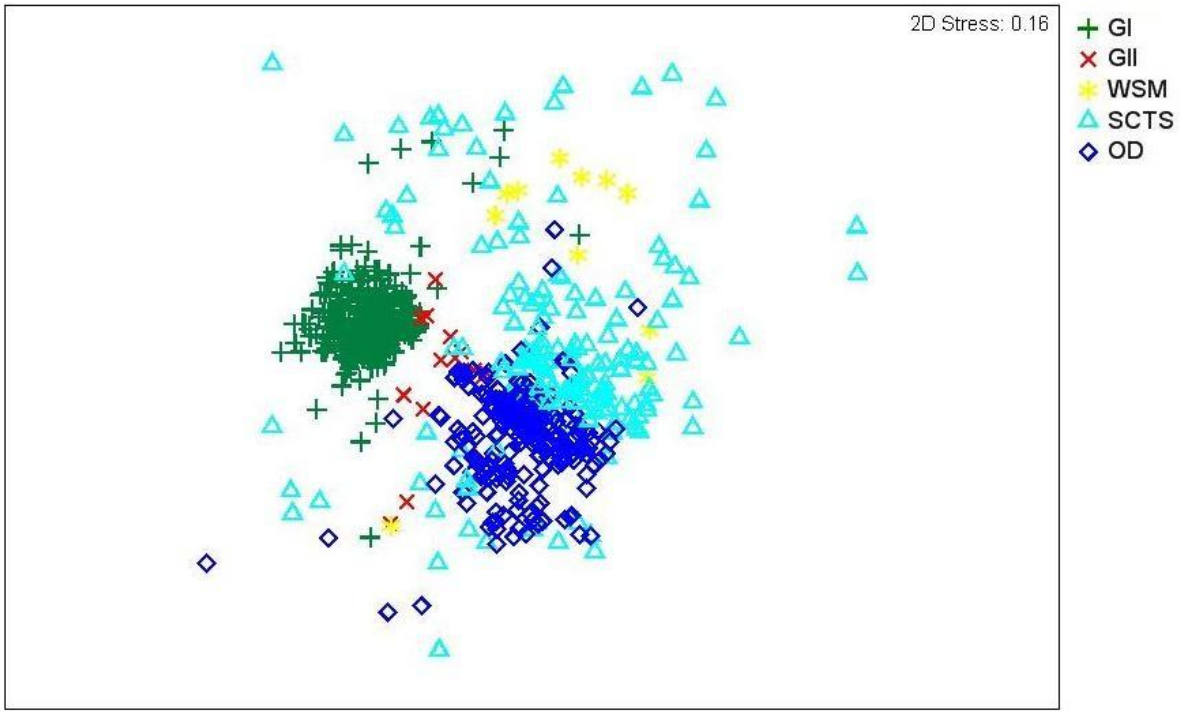


Figure 9: Multi-dimensional Scaling plot showing similarity among trawls from different surveys spanning 110 years of trawling activity. The ordination is based on specie composition. Continuum of the surveys from historical to recent (left to right) is visible. Data is shown following standardisation and root-root transformation and based on Bray-Curtis dissimilarity. GI= First Gilchrist Survey (1898-1904); GII= Second Gilchrist Survey (1922-1933); WSM=Wallace Small Mesh survey (Wallace et al. 1984); SCTS=DAFF South Coast Trawl Survey (1985-2010); OD=Observer Database (2002-2006).

An ANOSIM test of trawl grounds again gave a significant result (R=0.044, p=0.003). The trawl grounds that were most similar were again the Cape Infanta ground and the Algoa Bay ground. Least similar were the Cape Infanta and Mossel Bay grounds.

Examining survey dissimilarities while ignoring spatial effects gave a significant result (R=0.745, p=0.001). The least similarity was, as in previous analyses, between the Small Mesh Survey

and the other surveys' pair-wise tests (Wallace Small Mesh, First Gilchrist: R=0.968, p=0.001; Wallace Small Mesh, Second Gilchrist: R=0.922, p=0.001; Wallace Small Mesh, South Coast Trawl Survey: R=0.307, p=0.005; Wallace Small Mesh, Observer Database: R=0.895, p=0.001). Between the historical and the recent surveys, the First Gilchrist survey and the Observer Database were least similar (R=0.906, p=0.001). The South Coast Trawl Survey and the Observer Database were most similar (R=0.291, p=0.001).

Species dominating the trawl grounds followed a similar trend as that at higher taxonomic levels. Overall, trawl grounds were dominated by only a few chondrichthyan species: *Raja spp.*, *Squalus spp.*, *Callorhinchus capensis*, and *Narke capensis*. Skates (*Raja spp.*) and *Narke capensis* dominated the Cape Infanta ground. The Mossel Bay and Algoa Bay grounds were dominated by *Raja spp.* and *Squalus spp.*, but *Narke capensis* was also present on the Algoa Bay ground. In relation to Algoa Bay, Mossel Bay had more *Raja spp.* and more *Callorhinchus capensis*, but less *Squalus spp*. Cape Infanta catches contained more *Narke spp.*, but less *Raja spp*., *Squalus spp.* and *Callorhinchus capensis*. Algoa Bay had more *Squalus spp.* and Dasyatidae, whereas Cape Infanta had more *Raja spp.* and *Narke capensis*. Specie composition and comparisons are summarised in Figures 10 and 11.

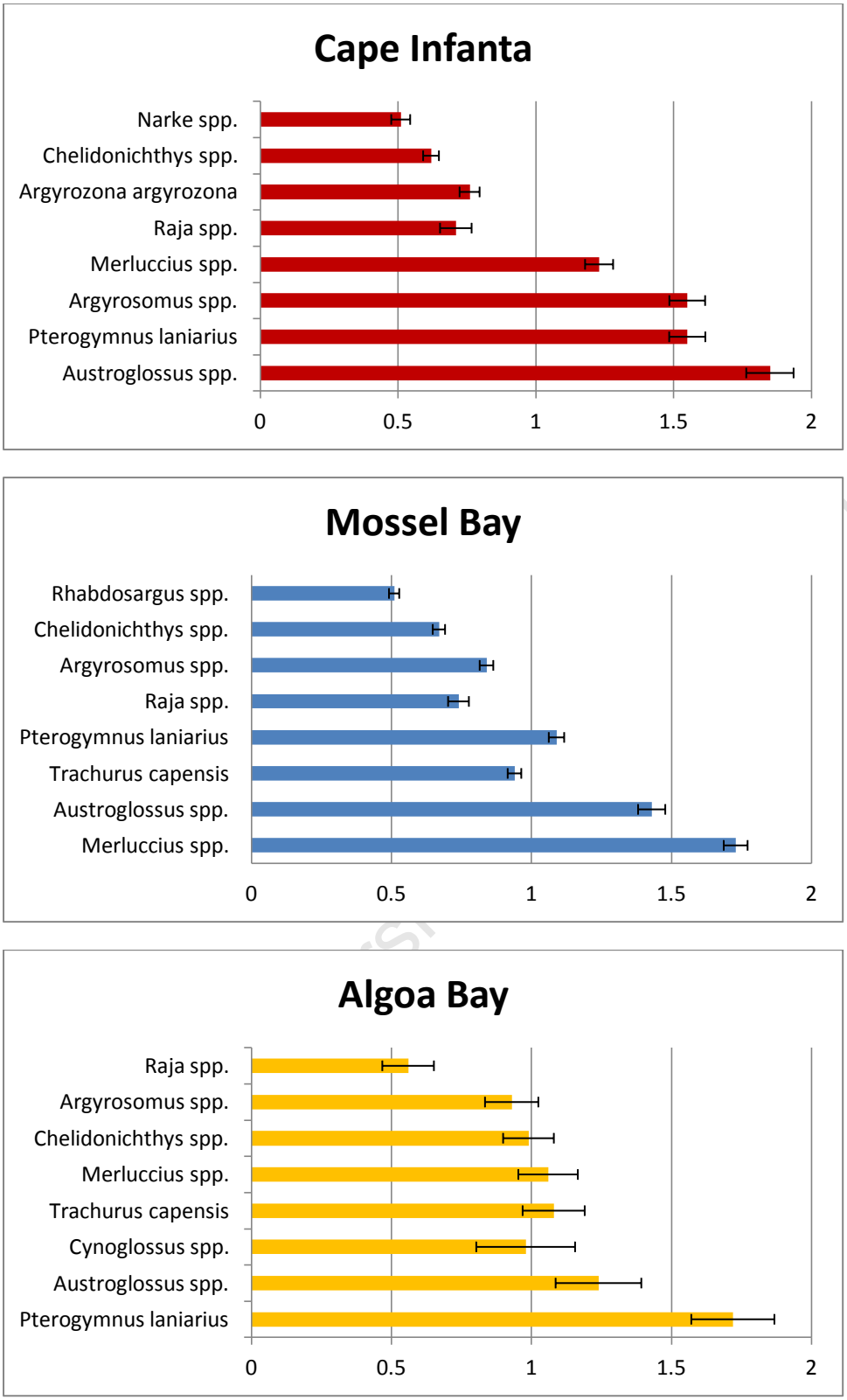


Figure 10: The results of a SIMPER analysis showing average relative abundance (standard error given in parentheses) at specie level within trawl grounds. Only species that contribute 95% to the similarity within a site are displayed. Average similarity was 38.14% for the Algoa Bay ground, 47.77% on the Cape Infanta ground and 38.50% on the Mossel Bay ground.

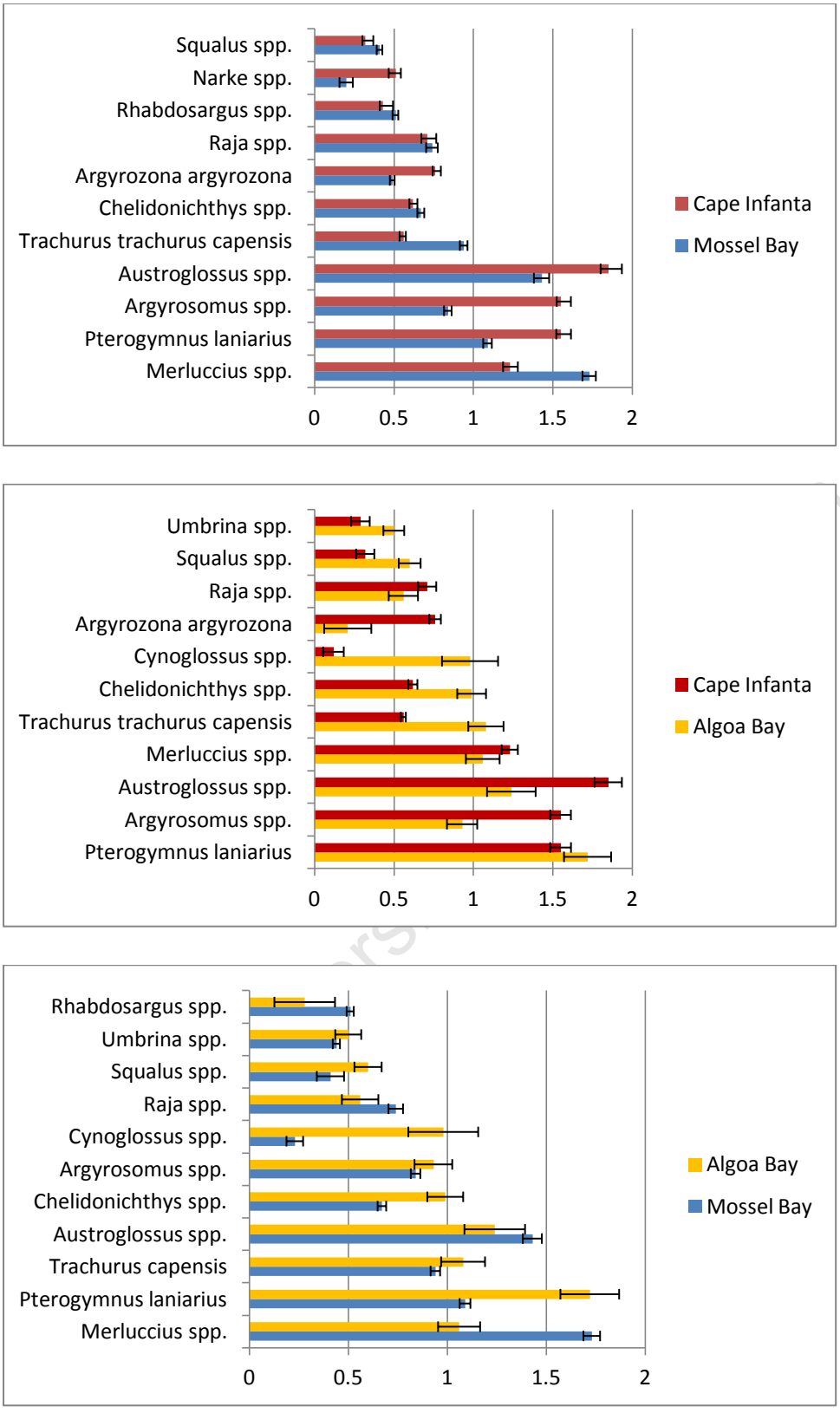


Figure 11: The results of a SIMPER analysis showing average relative abundance (standard error given in parentheses) at specie level among trawl grounds. Only species that contribute 95% to the dissimilarity among sites are displayed. Average dissimilarities are as follows: Cape Infanta/Mossel Bay: 56.54%; Mossel Bay/Algoa Bay: 59.58% and Cape Infanta/Algoa Bay: 56.04%.

Comparison among periods and trawl grounds

Order level

MDS plots show a clear separation between the lumped historical (First Gilchrist and Second Gilchrist) and the lumped recent surveys (South Coast Trawl Survey and Observer Database). Separation of trawl grounds is clearer in the historical surveys than it is in the contemporary surveys (Figure 12). The PERMANOVA results show that the effects of *TrawlGround*, *Period* and *TrawlGrid* were all significant, as were both interactions involving *Period* (Table 4). The results suggest real differences between periods, that these changes were not consistent between grounds, and that there was additional variability at the level of the grid-blocks.

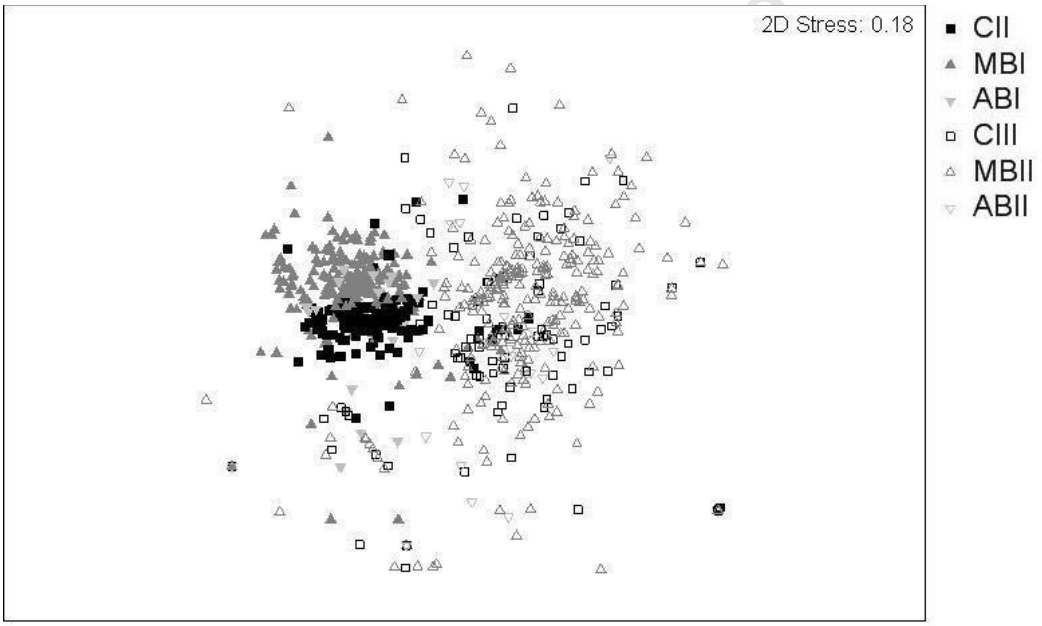


Figure 12: MDS plot of similarities among order composition in trawl catches with respect to the *PeriodGroup* and *TrawlGround* factors following root-root transformation. CI= Cape Infanta, MB=Mossel Bay, AB= Algoa Bay; I= First historical group containing the GI and GII surveys, II= Second historical group containing SCTS and OD surveys.

Table 4: Permutational Multivariate Analysis of Variance results for analysis at order level main effects are with the factors *PeriodGroup*, *TrawlGround* and *TrawlGrid*. Mixed tests are between *PeriodGroup* and *TrawlGrid* (clustered in *TrawlGround*). Pseudo-f is the statistic based on the ANOVA f generated by the number of unique permutations and P is the significance based on the permutations. Maximum unique permutations were set at 999.

Source	df	SS	ms	Pseudo-f	P (perm)	Unique Permutations
PeriodGroup	1	61080.00	61080.00	34.23	0.001	998.00
TrawlGround	2	12565.00	6282.30	2.66	0.028	998.00
TrawlGrid	16	46652.00	2915.70	3.87	0.001	997.00
PeriodGroup x *TrawlGround*	2	9475.60	4737.80	2.53	0.027	997.00
PeriodGroup x *TrawlGrid* (*TrawlGround*)	16	36197.00	2262.30	3.00	0.001	997.00
Residuals	722	544390.00	754.00			
Total	759	950980.00				

SIMPER results at the order level showed an increase in Chimaeriformes in the recent surveys relative to the historical surveys. Decreases were found in the Torpediniformes, Rajiformes and Squaliformes relative to the historical lumped surveys (Figure 13).

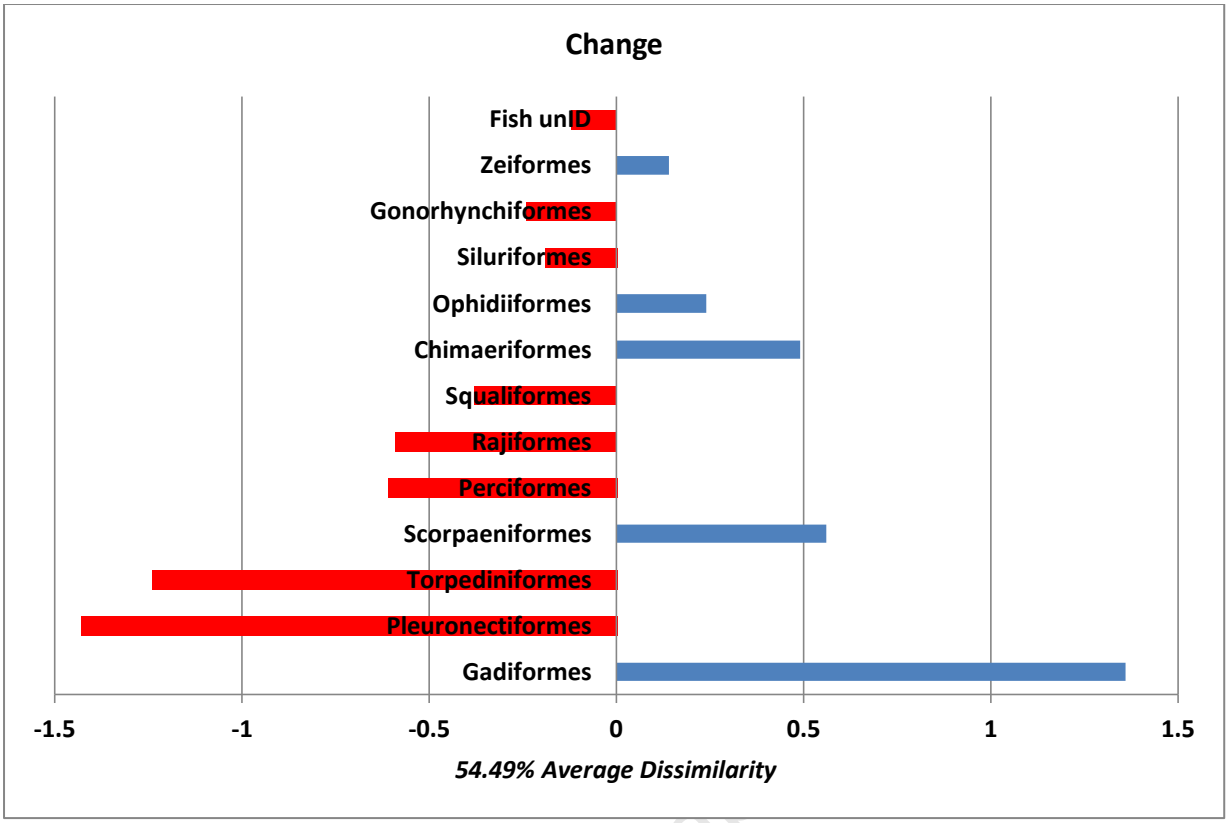


Figure 13: SIMPER analysis of lumped surveys at order level following root-root transformation. To obtain the difference between the two periods, the recent relative abundance value for each specie was subtracted from the historical value. Red bars indicate a decline in relative abundance, whereas blue bars indicate an increase. Average dissimilarity is the dissimilarity between the two periods (Period I and Period II) calculated by the SIMPER analysis drawn from the Bray-Curtis dissimilarity matrix.

Family Level

At the family level, separation according to the Period group is still pronounced. However, separation according to trawl grounds is now less clear, the three trawl grounds having been drawn together with increased taxonomic resolution (Figure 14). PERMANOVA results were once again significant for the main effects, but only the *Period* x *TrawlGrid* interaction term was significant (Table 5).

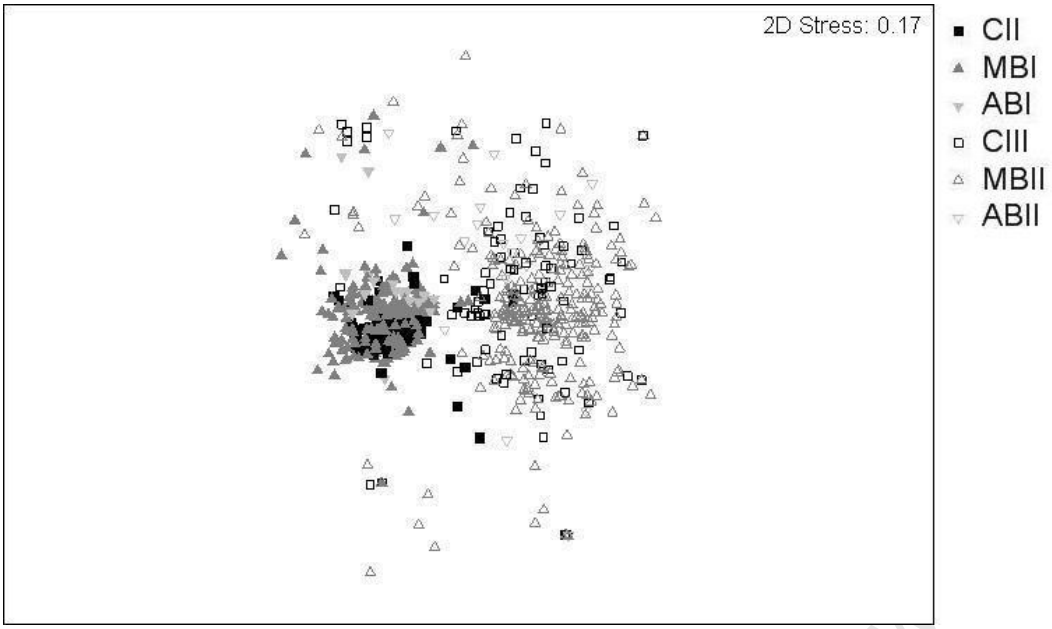


Figure 14: MDS plot of similarities among family composition in trawl catches with respect to the *PeriodGroup* and *TrawlGround* factors following root-root transformation. CI= Cape Infanta, MB= Mossel Bay, AB= Algoa Bay; I= First historical group containing the GI and GII surveys, II= Second historical group containing SCTS and OD surveys.

Table 5: Permutational Multivariate Analysis of Variance results for analysis at family level main effects are with the factors *PeriodGroup*, *TrawlGround* and *TrawlGrid*. Mixed tests are between *PeriodGroup* and *TrawlGrid* (clustered in *TrawlGround*). Pseudo-f is the statistic based on the ANOVA f generated by the number of unique permutations and P is the significance based on the permutations. Maximum unique permutations were set at 999.

Source	df	SS	MS	Pseudo-F	P (Perms)	Unique Permutations
PeriodGroup	1	96926.00	96926.00	32.04	0.001	997.00
TrawlGround	2	17796.00	8897.80	2.89	0.018	999.00
TrawlGrid	16	61632.00	3852.00	3.88	0.001	998.00
PeriodGroup x *TrawlGround*	2	12026.00	6012.90	1.86	0.077	999.00
PeriodGroup x *TrawlGrid* (*TrawlGround*)	16	65199.00	4074.90	4.11	0.001	999.00
Residuals	717	711490.00	992.32			
Total	754	1347000.00				

SIMPER analysis at family level revealed less Sciaenidae, Sparidae, Soleidae, Rajidae, Narkidae, Squalidae, Torpedinidae, Ariidae and Gonorhinchidae in the lumped recent surveys relative to

historical lumped surveys. However, there were more Merlucciidae, Carangidae, Triglidae, Callorhinchidae, Cynoglossidae, Ophidiidae and Zeidae in the recent surveys relative to the historical lumped surveys (Figure 15).

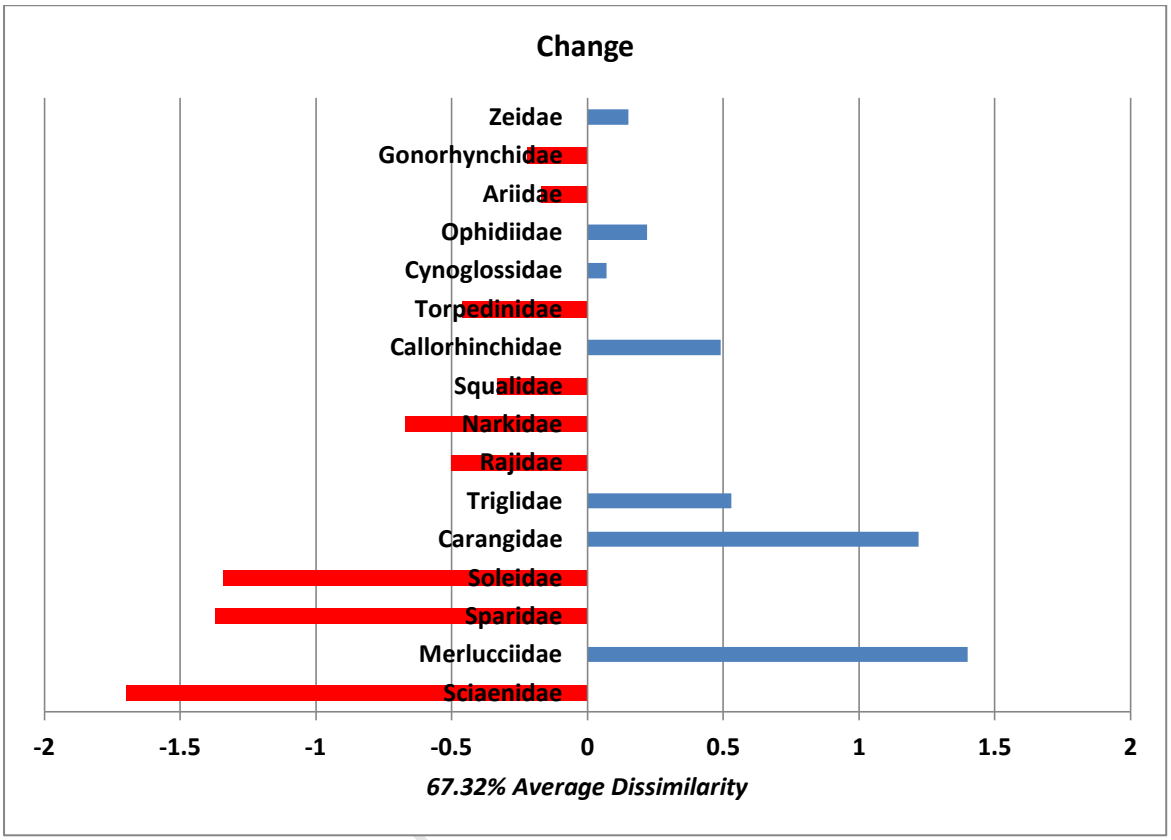


Figure 15: SIMPER analysis of lumped surveys at order level following root-root transformation. To obtain the difference between the two periods, the recent relative abundance value for each family was subtracted from the historical value. Red bars indicate a decline in relative abundance, whereas blue bars indicate an increase. Average dissimilarity is the dissimilarity between the two periods (Period I and Period II) calculated by the SIMPER analysis drawn from the Bray-Curtis dissimilarity matrix.

Specie level

MDS plots at specie level follow the same general trend as at order and family levels. Trawls cluster according to *Period*. Historical trawls show less variability in specie s composition than the recent ones (Figure 16).

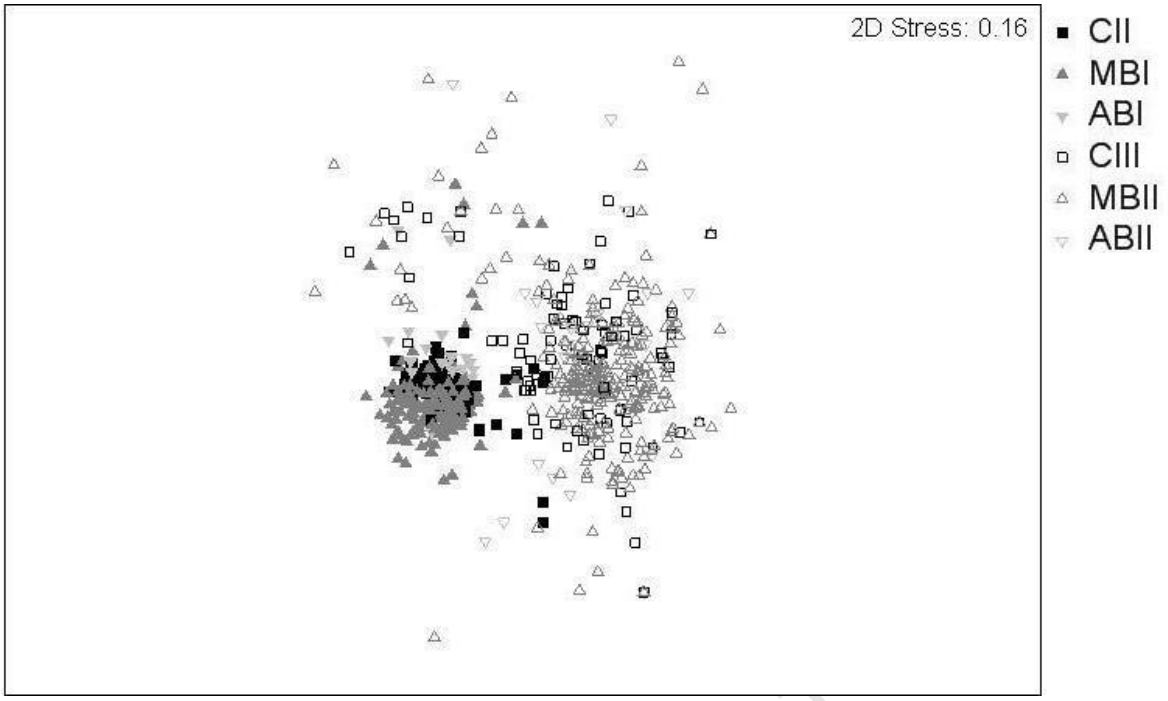


Figure 16: MDS plot of similarities among specie composition in trawl catches with respect to the *PeriodGroup* and *TrawlGround* factors following root-root transformation. CI= Cape Infanta, MB= Mossel Bay, AB= Algoa Bay; I= First historical group containing the GI and GII surveys, II= Second historical group containing SCTS and OD surveys.

The PERMANOVA result at the specie level was qualitatively identical to the family level analysis i.e. significant main effects and a significant interaction between *Period* and *TrawlGrid* (Table 6).

SIMPER analysis showed less *Raja spp.*, *Squalus spp.*, and *Torpedo spp* in the recent lumped surveys relative to the historical lumped surveys. There was an increase in relative abundance of *Callorhinchus capensis* in the recent surveys relative to the historically lumped surveys (Figure 17).

Table 6: Permutational Multivariate Analysis of Variance results for analysis at specie level main effects are with the factors *PeriodGroup*, *TrawlGround* and *TrawlGrid*. Mixed tests are between *PeriodGroup* and *TrawlGrid* (clustered in *TrawlGround*). Pseudo-f is the statistic based on the ANOVA f generated by the number of unique permutations and P is the significance based on the permutations. Maximum unique permutations were set at 999.

Source	df	SS	MS	Pseudo-F	P (Perms)	Unique Permutations
PeriodGroup	1	119980.00	199800.00	35.36	0.001	999.00
TrawlGround	2	20930.00	10465.00	2.99	0.005	999.00
TrawlGrid	16	69444.00	4340.30	3.83	0.001	996.00
PeriodGroup x *TrawlGround*	2	14111.00	7055.30	1.96	0.068	999.00
PeriodGroup x *TrawlGrid* (*TrawlGround*)	16	71613.00	4475.80	3.95	0.001	996.00
Residuals	721	816660.00	1132.70			
Total	758	1559600.00				

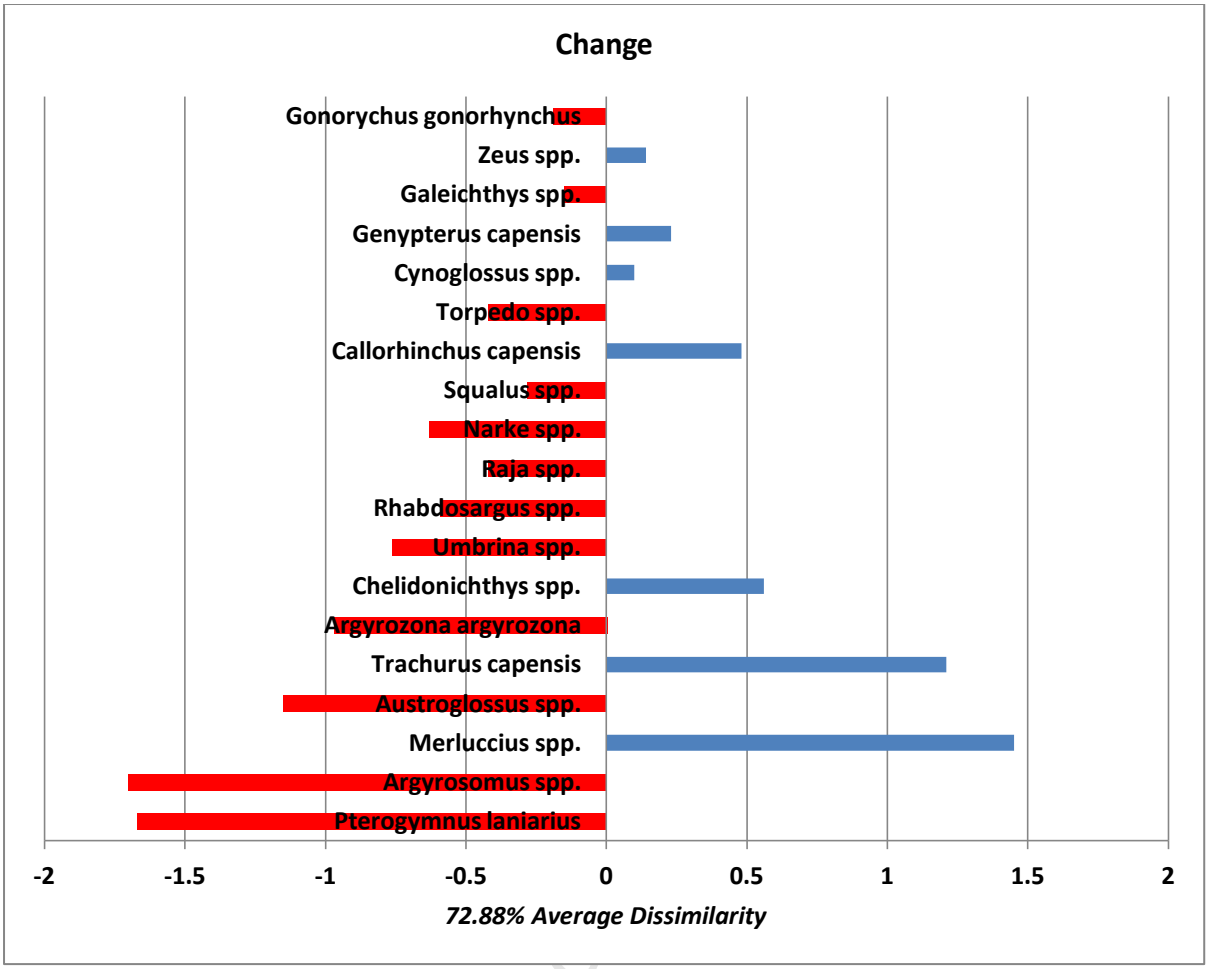


Figure 17: SIMPER analysis of lumped surveys at order level following root-root transformation. To obtain the difference between the two periods, the recent relative abundance value for each specie was subtracted from the historical value. Red bars indicate a decline in relative abundance, whereas blue bars indicate an increase. Average dissimilarity is the dissimilarity between the two periods (Period I and Period II) calculated by the SIMPER analysis drawn from the Bray-Curtis dissimilarity matrix.

Discussion

The historical surveys analysed here present a rare opportunity to compare the recent state of the Agulhas Bank ecosystem with a (near) baseline, pre-fishery state. Past studies on the Agulhas Bank have focussed on spatial and seasonal distributions of target species (Badenhorst & Smale 1991; Japp et al. 1994; Smale & Badenhorst 1991), but none of these gave insights into early or pre-exploitation conditions, except for Yemane et al. (2004) who examined long-term changes in line-caught species.

This is the first investigation into long-term abundance trends of species caught in South Africa's inshore trawl fishery. Even worldwide, few data of corresponding antiquity exist. Other known historical fishery datasets from around the world begin around the 1920s, roughly 20 years after the beginning of the Gilchrist surveys (Heath & Speirs 2011; McHugh et al. 2011).

Although historical data are invaluable management tools in themselves (Rijnsdorp et al. 1996), three points must be taken into consideration when comparing historical with recent data: 1) major changes in the ecosystem have been documented to occur with the first few years of exploitation (Jennings et al. 2006); 2) changes in technology will make fleets more efficient (Rijnsdorp et al. 1996); and 3) changes in the purpose of surveys will determine their methodology. The purpose for conducting surveys is in turn driven by fisheries management policies, which may also change over time. Of these three points, the most pertinent to consider are the changes in technology and management. Changes in the ecosystem are hopefully reflected in the data, as the historical surveys presented here largely preceded or coincided with the start of the fishery.

Long-term changes in trawl survey and design

Fishery surveys have been motivated by different objectives, which may have changed substantially over time. The five surveys analysed here were motivated by different objectives. The first historical survey was an exploratory survey in search of trawl grounds, prior to the development of a commercial fishery. Soft-bottom grounds suitable for trawling on the South Coast were extensively sampled for the profitable East Coast sole *Austroglossus pectoralis* and other marketable resources. The surveys also served as a marine biological survey, which accounts for the exceptional thoroughness of the data and species descriptions. Having mapped the resources of the inshore ground, the second Gilchrist survey used a more powerful vessel to conduct trawls on the East and West Coasts in deeper waters, although there was some geographical overlap in the surveys. All fish species in the catch were counted until 1933.

Following 1933, when fishery surveys took procedure over marine biological surveys, all surveys focussed on economically important species. This lead to the recording of bycatch to be limited to marketable species. In recent years (1985 onwards), multi-specie management policies and concerns about bycatch led to the recording of the entire catch in surveys to be resurrected.

The main focus of the South Coast Trawl Survey from 1985 was to calculate Catch Per Unit Effort rates as abundance indices primarily for hake and other commercial species (Glazer & Butterworth, 2002). A random stratified survey design was employed, as opposed to the systematic explorations of earlier times.

In contrast, the Wallace Small Mesh Survey (Wallace et al. 1984), was again an exploratory attempt to locate nursery areas of economically important species and estuarine-associated species along the South Coast.

The observer programme was designed to quantify the total pre-discard catch, and the discards of the commercial trawl fleet. Although commercial vessels were randomly selected for the observer deployment, the passage of the commercial vessels was by no means random and was far more restricted than any of the surveys of the inshore ground.

These differing objectives and designs affected the execution of surveys and the comparability of data. A comparison over time had to be restricted to common grounds, to remove confounding influences of geography. This was facilitated by detailed position data at the level of individual trawls. Although navigational technology improved substantially over the period of interest, the likely errors were sufficiently small to allow for comparisons with a 5 by 5 minute framework. This approach has been taken by other studies of historical-contemporary comparisons (McHugh et al. 2011). A dual spatial scale was used in the models to estimate the effect of habitat at the micro-scale (grid block) level within larger grounds, and then to compare differences between the grounds. The grid blocks represented potentially different habitats on the trawl grounds, although these could not be described and classified, and were therefore treated as random and uncrossed (with trawl ground) effects.

The search for common ground led to the exclusion of most survey data from this analysis, and effectively discounted the problem of differing survey designs. Two problems remain, namely gear differences and taxonomic resolution in the recordings, of which the former was the most problematic.

Inconsistencies in gear and trawl practice

The power of the vessel and size of the trawl net would have had a strong influence on the quantity, and to a lesser extent, specie composition of the catch. For example, the South Coast Trawl Survey had a much higher average Catch per Unit Effort (Fish per hour, Table 2), due to the larger net size and greater power of the vessel. The former problem was discounted in this chapter by standardising the data to remove the effects of absolute quantity, and to restrict comparisons to specie composition. The velocity of the towed net would influence particularly the number of large, swift species, and flatfishes which lie on or buried in the superficial sediments. The comparison of net speeds (Chapter 3), however, did not indicate substantial differences. Although the power of the vessel changed markedly over the years (but not within surveys), trawl velocity was maintained to some extent by using appropriately sized nets consistent with vessel power. Nevertheless, differences in species composition need to be checked for the possible influence of vessel power.

Related to power and net size is mesh size, which influences drag, velocity and the retention of small fish. Some differences did exist, despite the 75 mm standard being enforced since 1933 on the trawl grounds. The two exceptions are the Wallace Small Mesh Survey and the South Coast Trawl Survey, both of which used cod-end liners of 12 mm and 35 mm respectively. This discrepancy likely caused the outlying position of the Wallace Small Mesh Survey, and its elimination from the PERMANOVA model. The net liner on the South Coast Trawl Survey would have retained smaller fish than earlier surveys and commercial trawls, but I argue that the longer trawl duration of the latter would lead to a blocking of the net, thereby effectively allowing the retention of small fish. In effect therefore, trawl duration and mesh size work against each other with regards to specie and size composition. Changes in specie composition among the surveys will need to be checked for the possible influence of these factors.

Another issue related to the duration of the trawl is its influence on diversity in individual hauls. Trawls of longer duration cover more varied ground (Alverson et al. 1996), and may catch a greater variety and different mix of species than trawls of shorter duration. Trawl time is significant in that larger fish will take longer to tire of swimming in front of the net than smaller fish. Thus, a shorter trawl time will have a higher proportion of small fish (Jennings et al. 2006). The trawl time of the South Coast Trawl Survey and the Small Mesh Survey were standardised to half an hour and 10 minutes respectively. This is in contrast to the historical surveys and the fishing industry trawls, where trawl times vary but were generally between 2 to 3 hours (Booth & Hecht, 1998).

The likely effect of trawl duration is the influence on variability. Those surveys with the lowest trawl duration (South Coast Trawl Survey and Wallace Small Mesh), were more variable than those with longer trawl times. The South Coast Survey trawls consistently had the lowest similarity score in the SIMPER analysis, whereas the first historical survey had the highest over all three levels. This indicates variability in the catch of the recent surveys and a more uniform catch in the historical and the industrial data. The observer data were less variable than the survey data, possible because these were full-length trawls that were sub-sampled. The sub-sampling effectively meant that rare species would be detected less often, thereby reducing the variability in the root-root transformed specie composition.

McHugh et al. (2011), and Greenstreet & Hall (1996), adopted an experimental approach to overcome the biases listed above by repeating earlier surveys using either similar or identical gear and identical trawl durations. Such experimentation was beyond the means of this investigation, but would certainly warrant the effort if sufficient resources could be secured. Other methods of accounting for changes in management, which include ships' power, were used by Rijnsdorp et al. (1996). A popular method of standardisation for changing variables when comparing different data sources is General Linear Models or General Additive Models (Maunder 2004; Braccini et al. 2011; Campbell 2004; Bailey et al. 2009). Although these are commonplace, the authors conclude that the only way to be positive of comparison is to repeat the trawls in every detail.

Effects of taxonomic resolution

The dangers of lumping species into higher taxa were outlined by Dulvy et al. (2000). The authors state that lumping may hide the declines of some species while giving the overall impression of a stable trend. This is especially true for species of similar appearance and members of the same genus or family.

Although lumping occurred in some of the surveys, results over the three taxonomic levels reflected the same trend. With increasing taxonomic resolution, significance generally increased. Significance was found for the single factor PERMANOVA tests at all three levels. Results for the interaction factors of *PeriodGroup* and *TrawlGrid* were significant at both the family and specie level. The

discrepancy at order level may be due to the low taxonomic resolution, although both single factor tests were also significant at that level.

Despite the fact that lumping posed a potential hurdle in the accuracy of the data, the consequently repeated results are an indication that they are at least qualitatively correct. In addition, the trends found here over time generally match those found in other studies from other trawl fisheries around the world, although other studies cover a smaller geographical range than this study (e.g: McHugh et al. 2011; Christensen et al. 2003).

Differences among and within trawl grounds

Despite being significant, dissimilarities among the trawl grounds were all within 10% similarity of each other in the Bray-Curtis matrix as shown by the ANOSIM tests. Mossel Bay was distinguished at all taxonomic levels by the presence of hake (*Merluccius spp.*) whereas Algoa Bay and Cape Infanta were most similar due to the presence of sole species (Pleuronectiformes). The latter species group was influenced by the lumping with other flatfishes (most notably *Cynoglossus zanzibarensis*), but was not so for hake, which vastly dominated the Gadoids.

The factor *TrawlGrid* was used as a proxy for habitat, which may explain some of the variability seen in the analysis at this highest attainable spatial resolution. The significant result at all three taxonomic levels of the *TrawlGrid* factor indicates a varied substrate even within the trawl grounds. Significant differences were found for all other single factor tests at all taxonomic levels. However, in the mixed model, changes over time in *TrawlGround* were significant only at order level. It is likely that the variation at family and specie level is low relative to that at order level. Changes over time in *TrawlGrid*, on the other hand, were significant at all taxonomic levels. Changes in catch composition over time have therefore been greater in the micro- (*TrawlGrid*) than on the macro-scale (*TrawlGround*).

The presence of similar trends at all taxonomic levels indicate that the changes seen in the specie composition reflect real changes among the grounds over time, regardless of the difficulties in species recording.

Differences over time

Although a continuum in the MDS visualisation of the five datasets was shown to exist, differences in the execution of the surveys suggested that they were not directly comparable. However, even after standardising for trawl ground, eliminating effects of varying catch quantity, and exploring the uncertain effects of taxonomic resolution, differences over time were found to be highly significant.

Although sole was the target catch initially, hake was soon the predominant catch in the inshore trawl fishery. Additionally, all chondrichthyans, with the exception of the Chimaeriformes (Callorhinchidae: *Callorhinchus capensis*), showed a declining relative abundance between the two periods. This is despite the presumption that large fish (e.g. silver kob: *Argyrosomus inodorus*) and chondrichthyans should have been underrepresented in the early trawls as ships power, although not necessarily trawl velocity, was less in the early period. As they were actually highly represented in this early period, and trawl velocity was found to be comparable between surveys, this indicates a decline in absolute abundance rather than a decrease in a relative proportion of catch composition.

In addition, diversity decreased slightly at both the family and specie level between the periods. The number of families causing the top 95% similarity between periods went from 8 to 7, whereas at specie level it dropped from 10 to 8. Six Orders were present in both periods.

The trends exhibited over time reflect the trends in other studies. For example, Christensen et al. (2003) showed large declines in high trophic-level fish by modelling North Atlantic ecosystems between the years 1880 and 1998. Although they focus on pelagic species, the time period is comparable to the one analysed here. Other studies of temperate benthic systems show similar declines in chondrichthyans and large fish: McHugh et al. (2011) in the western English Channel, Greenstreet & Hall (1996) in the North Sea; and Christensen et al. (2003) in the North Atlantic.

The changes that were observed are discussed in detail below at the level of each specie or species group.

Specie-specific trends

Three teleost species and one chondrichthyan specie that were common in the surveys showed increases, whereas three teleost and three chondrichthyan species showed trends of decreasing relative abundance.

Declines in abundance of species impacted by fisheries may be caused by a number of reasons. Primarily, it is the increased mortality brought by fishing that decreases the population beyond its reproductive capacity. The decline brings cascading effects with it, such as a loss of spawner biomass and a loss of BOFFF (Big Old Fat Fecund Female, Berkeley et al. 2004) fish, shifts in the age at onset of key physiological developments and changes in the genetic compositions of the stock (Jennings et al. 2006).

Increases have seldom been pinned down to a single factor. Competitive release (Dulvy et al. 2000), predation release (Daan et al. 2005) and niche exploitation are known causes. Increases also may lead to changes in the distribution and physiological parameters.

Hake

Hake relative abundance increased in this study. The increase is most likely due to actual decreases in the proportion of other species in the catch composition. As other traditional species such as sole (*Austroglossus spp.*) and kob (*Argyrosomus spp.*) decrease, the proportion of hake caught is automatically increased.

At the moment, the *M. capensis* stock is deemed to be well managed at 50% of its baseline abundance (Rademeyer et al. 2008), and forms the largest part of the catch assemblage (Rademeyer et al. 2008). Although hake is a demersal specie that resides in cold water, it is fast growing and highly fecund (Osborne et al. 1999). These characteristics may underpin its productive capacity.

Hake is a fairly opportunistic specie, feeding off crustaceans while young, but progressing toward a piscivorous diet as they grow, taking mainly horse mackerel and smaller hake (Pillar & Wilkinson, 1995). The ability to vary its diet may add to its resilience.

Horse mackerel

Horse mackerel relative abundance increased overall between the two discreet periods. However, relative abundance indices of horse mackerel differed between the South Coast Trawl Survey and the Observer Database. Either good targeting of hake (or high discards of horse mackerel) in the industry cause the relative abundance here to be higher than that found in the recent surveys (Japp et al. 1994). The difference in mesh size between these data sets may also explain the preponderance of horse mackerel (a small-bodied fish) in the surveys. Despite decreased landings between 1985 and 1995 in the Eastern Cape, it is still deemed to be one of the largest fish resources on the Agulhas Bank (Booth & Hecht, 1998).

The increase of the relative abundance indices found in this study may stem from the biology and secondary effects of trawling. Horse mackerel is a relatively fast-growing specie which is short-lived. Fish attain a maximum age of 10 years, and feed mainly off euphausid shrimp and copepods (Hecht, 1990). Due to its semi-pelagic lifestyle and food sources, it is not always subjected to trawling pressure. Additional release from predation pressure (e.g. from silver kob *Argyrosomus inodorus*) may be a main reason why these fish have become more dominant in the catch composition.

Gurnards

The lumped category of the gurnards (*Chelidonychthes spp*.) showed a remarkaeble increase in relative abundance, especially as stocks of the larger gurnards (*Chelidonychthyes kumu* and *C. capensis*) have been deemed stable (Japp et al. 1994). The results presented raise the question if the lesser gurnard, *C. queketti* has accounted for most of the increase in gurnard relative abundance.

Despite high mortality in the trawls, a varied and adaptable diet and small size would fit trends seen in other studies for small, opportunistic species (e.g: Greenstreet & Hall, 1996). As such, secondary effects of trawling such as niche exploitation may responsible for the increases in gurnard relative abundance. For example, a study of the behaviour of *Eutrigla gurnardus* showed that it increased the amount of invertebrates (mainly amphipod crustaceans) ingested in recently trawled areas (Kaiser & Spencer, 1994).

Studies from the North Sea have found that a decrease in gurnards (mainly *Eutrigla gurnardus*) has taken place over time (Greenstreet & Hall, 1996). This stands in contrast to this study, where the lumped group "gurnards" has increased its relative abundance. However, the European studies focus on one common specie in the North Sea (Rijnsdorp et al. 1996), whereas three species are common in the Agulhas Bank inshore trawl industry (*Chelidonychthyes queketti*, *C. kumu* and *C. capensis*) (Heemstra & Smith, 2002). In contrast to European studies, little research has been done on the three gurnards native to the Agulhas Bank (Japp et al. 1994). However, it is likely that the diet will be similar to that of *E. gurnardus*.

St. Joseph shark

The St. Joseph shark has also shown an unexpected increase in relative abundance, despite concerns raised as to destruction of egg-laying grounds by trawlers, the capture of young individuals (Freer & Griffiths, 1993) and the lack of a deep-water refuge (Kroese et al. 1995). A co-gener from Australian waters (*C. milli*), was declared depleted following similar fishing patterns (Fowler et al. 2005). The exploitation of resources exposed by trawling coupled with a relatively fecund biology may together explain the relative increase observed.

Callorhinchus capensis feeds on benthic bivalves and crustaceans (Freer & Griffiths, 1993). It is substantially more fecund than other chondrichthyans, with mating taking place more than once per season. Females are therefore able to lay up to 20 eggs from the age of seven to twelve years of age (Freer & Griffiths, 1993).

Silver kob

The declining trend found in silver kob (*Argyrosomus inodorus*) tie in well with what has been found in other studies around South Africa concerning linefish species. Linefish such as silver kob have shown declines in recent history (Yemane et al. 2004). Stock status is still a concern as silver kob is still a regular feature in the inshore trawl bycatch (Booth & Hecht, 1998). Absolute abundance indices were calculated by Smale & Badenhorst (1991), and showed a noteworthy decline. Despite this, in the Eastern Cape, no significant trends were found for silver kob (Booth & Hecht, 1998).

Silver kob has been the mainstay of linefishermen since the industry began (Griffiths, 2000), and was also one of the most important economic resources exploited in the inshore trawl. Contemporary relative abundance levels have remained much lower than historical baselines, and are most likely due to the long-term exploitation of a low-fecundity specie by two fisheries.

Soles

It was theorised that the perceived decline in relative abundance shown here could be due to an increased trawl velocity. Increased trawl velocity would cause the net to skim over the substrate, rather than dig in. As sole burrows into the sediment, they may escape below the leadline. However, investigations into the trawl velocity (Chapter 3) have shown that there has been no significant increase in velocity between the historical surveys and the industry. Thus, the trend in sole relative abundance likely reflects a similar trend in actual abundance.

Sole (*Austroglossus pectoralis*) and tonguesole (or sandrat: *Cynoglossus spp*) are generally found inshore in waters less than 100 meters deep (Badenhorst & Smale, 1991; Booth & Walmsley-Hart, 2000), making them susceptible to trawling. Although a decline in abundance was found by Badenhorst & Smale (1991), their study covers too short a time period to confirm a long-term trend. In addition, the decline was due to economic factors rather than bio- or ecological factors.

A depletion of young sole in the early exploitation of the trawl grounds off Cape Infanta and southeast Mossel Bay and the modification of the benthic habitat may have lead to a decline in productivity at an early stage in the fishery (Scott, 1949).

Panga

Panga was considered to be "*one of the most plentiful Sparid fishes in South Africa*" (Heemstra & Smith, 2002). Despite this, a decrease in relative abundance was found in this study. Panga was heavily targeted by the Japanese trawling fleet prior to the declaration of the Exclusive Economic Zone (Smale & Badenhorst, 1991; Booth & Hecht, 1998). The data presented here show

that the trends found by Badenhorst & Smale (1991) and Booth & Hecht (1998), have been a continuation of trends found in historical times, and are not simply a recent phenomenon.

The depletion was accompanied by a decrease in maximum observed length (Yemane et al. 2008). This supports Booth & Hecht (1998), who showed that at least on the east Agulhas Bank, fish are recruiting into the fishery at a smaller size.

Skates

As in this study, skates have shown a significant declines in other parts of the world (e.g: Cedrola et al. 2005; Dulvy et al. 2000; Swain et al. 2005; Walker & Hislop, 1998). The best studied area is the North Sea, where long-term data are available (Walker & Hislop, 1998; McHugh et al. 2011; Philippart, 1998), and the trends on the Agulhas Bank reflect those found there.

Due to their large body size, skates are especially susceptible to trawl fisheries (Dulvy & Reynolds, 2002). However, the lumping of skate species into a general category "Skates" often confounds specie-specific conservation efforts. Grouping in this manner was found to mask declines in species with a large body size while simultaneously, smaller species showed a population growth (Dulvy et al. 2000). The authors attributed the increases to competitive release over food sources. Most skates share a similar diet, and the decline due to fishing mortality of large species allowed smaller ones to utilise those resources.

On the Agulhas Bank, only the survey data give accurate identification for some skates (Leslie, 2008). Trends are available for six individual species and one lumped category. The trends roughly follow those implied by (Dulvy et al. 2000), with large species such as *Raja alba* showing a decline while other species (*R. pullopunctata* and *R. wallecei*) show increases. A generally stable trend is shown by the lumped "skate" category (mainly *Raja spp.*). A shortcoming of these trends is the relatively short time covered compared to long-term changes.

Spiny dogfish

Spiny dogfish showed a decline in relative abundance between the two periods. Dogfish of the genus *Squalus spp*. form a large part of the ecosystem on the Agulhas Bank, with Japp et al. (1994) estimating that it has the fifth largest biomass on the Bank. Due to this, it is also a frequent feature in trawling bycatch assemblages (Japp et al. 1994; Walmsley et al. 2007b). However, it has shown declines in relative abundance. Presently it is not retained and entirely discarded at sea due to its small size, although it used to be marketed three decades ago.

The trends presented here conform to those of other spiny dogfish stocks from around the world. Dogsharks have a history of being misunderstood and mismanaged (Gallucci et al. 2009). Especially in North America they are well studied, following a series of increases and declines in landings due to an oil fishery, subsequent eradication programmes and declines following stock depletion. These species show relatively high site fidelity, without moving more than a few kilometres away from their tagging point (Gallucci et al. 2009). In respect to the Agulhas Bank population, it could mean it is relatively isolated, with little recruitment from outside the Agulhas Bank area.

Torpediniformes

Electric rays have declined in relative abundance on the Agulhas Bank. As little biological data exists for the South African species, comparisons to other studies must be made.

The reproduction of two species of electric rays of the genus *Torpedo* were analysed by Consalvo et al. (2007). Both species were caught as bycatch in soft-bottom in the trawl fishery off the Italian coast. One of them, *Torpedo marmorata*, is a Mediterranean and Atlantic species with a range that extends to South Africa. The authors suggest that differences in the size of the two *Torpedo* species may be due either to local variation in species morphology representing differences in food availability or sexual segregation into different areas and depth strata. Both species also had a larger weight increase per size increment in the female portion of the samples (Consalvo et al. 2007), meaning that females had a faster growth rate until mature. However, *T. marmorata* gained a larger size than both males of the same specie and *T. torpedo*, indicating a larger energy requirement during gestation. The reproductive cycle lasts 2 years, with gestation lasting 9 to 10 months. The authors conclude that both rays exhibit strong k-selected reproductive

strategies, with *T. torpedo* more adapted to a changing environment whereas *T. marmorata* being more adapted for a stable environment.

The implication for this on the Agulhas Bank is that the decline in Torpediniformes is likely due to fishing pressure coupled with low fecundity and an inability of *T. marmorata* to adapt to changes in the environment brought on by trawling.

Conclusions

Historical data was used to test the null hypothesis that no change had taken place in the species assemblage of the Agulhas Bank inshore trawl grounds. To this effect, analyses were conducted between 5 different surveys and three common trawl grounds. Data was then lumped to form two distinct periods separated by more than 110 years of intense trawling activity.

Changes in relative abundance were found in a number of species commonly caught as bycatch by the inshore trawl fishery. Some species were known to have, or were expected to decline, for example, the linefish (Yemane et al. 2004). However, especially the chondrichthyan assemblage was found to have decreased from historic near-baseline levels. An exception to general trend of decline in the chondrichthyan assemblage was the increasing trend of *Callorhinchus capensis*.

Although generally deemed a compliant and well-managed fishery, these results prove that trawling has impacted the specie assemblage over the long-term, and that the existing single-species management has been ineffective when looking at changes in the catch composition.

The long-term shifts in catch composition of the South African inshore trawl industry generally conform with trends seen in other temperate shelf trawl fisheries around the world (Heath & Speirs, 2011; Jennings et al. 1999; McHugh et al. 2011; Myers & Worm, 2003; Tavares & Arocha, 2008), and is consistent with theoretical predictions based on life-history theory and productivity. Species with a large maximum size (e.g. silver kob), low reproductive output and slow maturation (e.g. Torpediniformes) have decreased, whereas small species (e.g. horse mackerel), and those with an adaptable diet (e.g. hake), have increased their relative abundance. Species that seem to break these trends (e.g. *Callorhinchus capensis* and gurnards), are most likely

subject to secondary effects of trawling, and will require more data to pinpoint the interactions taking place.

CHAPTER 3: CHANGES IN THE DENSITY OF CHONDRICHTHYAN SPECIES ON THE AGULHAS BANK OVER A 100 YEAR PERIOD

Abstract

Changes in the absolute abundance of chondrichthyan species on the inshore Agulhas Bank were investigated by comparison of historical and recent trawl survey data. Swept area density was calculated from catch data from four surveys that took place within two time periods, 1898 to 1933 and 1985 to 2010. To account for changes in fishing power, differences in trawl velocity among surveys was tested by means of a Kruskal-Wallis test. Although significant differences were found, these corresponded to the manner in which velocity was recorded, and to a lesser extent on the actual velocity, which probably increased only slightly between the periods. Significant trends in abundance were found in most species. Overall declines were found in *Carcharhinus spp.*, *Dasyatis spp.*, *Narke capensis*, *Raja spp.*, *Squalus spp.*, and *Torpedo spp*. The only chondrichthyan to increase in overall abundance was *Callorhinchus capensis*. Changes in abundance followed predictions based on life-histories.

Introduction

Multivariate analyses were used to discern trends in specie assemblages in trawl catches on the Agulhas Bank over a 100 year period (Chapter 2). Significant changes in specie composition were detected, but these could not indicate absolute trends (Clarke & Gorley, 2006). To estimate abundance, it is necessary to use univariate indices of abundance.

In most contemporary fishery management scenarios, data come from surveys conducted within the last 40 years. However, assessments based on recent surveys do not give direct estimates of pre-exploitation abundance. The use of historical data gives the advantage of estimating baseline abundances from a time before fishing substantially altered fish abundance. This is also true for

bycatch species which are usually neglected in conventional single-specie management approaches (Pope et al. 2000).

In cases where older historical data are found and used, the standardisation of fishing gear and catchability is more problematic, given substantial changes in gear efficiency and fishing techniques. The most relevant examples include: 1) the replacement of coal powered steam engines by diesel shortly after World War Two, giving trawlers more power and range; 2) depth sounders were installed on fishing boats, and modified to be used as fish finders; 3) synthetic polymer nets were more durable than traditional natural fibre; 4) the methods of ship positioning advanced from land bearings to radio beacons, Decca and eventually, with the advent of satellite communications, to global positioning systems (GPS); and 5) improved communication. These advances made fishing vessels increasingly efficient at finding and exploiting fish, thereby changing the catchability coefficients and rendering the nominal Catch per Unit Effort (CPUE) records unreliable as indicators of abundance (Jennings et al. 2006).

One of the methods fisheries scientists use to standardise survey data to a comparable level is the Swept Area function. The abundance of fish is estimated within the area fished by the net (Walsh, 1996). This estimate is then scaled up to the entire area covered by the survey, enabling comparisons in the density of fish. Comparison of these densities over time gives scientists an idea of possible impacts that fishing has had on populations. To some extent, this takes ships power into account, unlike calculations based on uncorrected CPUE. In comparison, CPUE is a measure of catch rate, not abundance. The swept area function, however, does not account for trawl speed *per se*. Ships with less power might trawl at lower velocities, allowing faster fish to outswim the net (Jennings et al. 2006).

Chondrichthyans exhibit shifts in abundance, assemblage and maximum size when subjected to chronic fishing pressure. Some of the best examples of these changes come from the North Sea, where bottom trawling has been conducted and documented over a long time period (Greenstreet & Hall, 1996; Heath & Speirs, 2011; McHugh et al. 2011; Rijnsdorp et al. 1996; Walker & Hislop 1998).

Despite concerns over the conservation of bycatch species, chondrichthyan densities have not been accurately researched on the Agulhas Bank. There are trends available for a few chondrichthyan species on the East Coast of South Africa (e.g. Dudley & Simpfendorfer, 2006), but these were not affected by trawlers. The assessment of bycatch species has been neglected, as emphasis has been placed on economically exploitable species of teleost fish (Badenhorst & Smale, 1991;

Smale & Badenhorst, 1991). To date the most widely cited assessment of bycatch species is an analysis of linear trends in nominal CPUE of all species caught in the South Coast Trawl Surveys within the past four decades (Leslie, 2008). These could not approximate changes from baseline values.

In general, very little is known about the status of chondrichthyans on the Agulhas Bank. Following 110 years of sustained fishing pressure (Payne and Crawford, 1989), significant changes in non-target species are expected. This chapter will be the first study to focus exclusively on chondrichthyan density trends over time on the Agulhas Bank. Baseline approximates will be compared to recent density estimates using swept are calculations.

Methods

Catch data from four separate surveys on the inshore Agulhas Bank were prepared to provide comparable indices of density for the numerically dominant species. These surveys covered the years 1898 to 1904 (Gilchrist 1898, 1899, 1900, 1901, 1902, 1903, 1904), 1922 to 1948 (Gilchrist & Von Bonde 1923, 1924, 1925, 1926, 1927, 1929a, 1929b, 1930; Von Bonde 1932, 1933a, 1933b, 1934, 1935, 1936, 1937, 1938, 1939, 1940, 1941, 1942, 1943, 1944, 1945, 1946, 1947, 1948, 1949) and more recently from 1985 to 2010 and 2002 to 2006 (Attwood, Petersen, & Kerwath, 2011).

Historical data 1989 to 1904 and 1922 to 1948

The two early surveys were intended to provide the fishery authority and fishing industry with assessments of the quantity and composition of catches that can be expected on various grounds and in most respects represents initial trawls on the respective grounds. Positioning was accomplished by taking land bearings, celestial references or radio-positioning. Trawls varied in duration from 30 minutes to 3 hours. The vessels that were used included the *FRV Pieter Faure*, *SS Pickle*, and *FRV Africana*, all of which were steam-driven (Lutjeharms & Shannon, 1997).

Observer data 2003 to 2006

The offshore resources observer programme operated from September 2002 to October 2006. Observers were stationed on commercial hake and sole trawlers to record the pre-discard catch in the trawl net. Thirty-four vessels, between the sizes of 15 m and 30 m, were part of the inshore fleet, all of which were diesel-powered. Only 25 were sampled (Attwood & Peterson, 2010). Catch was sub-sampled and the mass and number of each specie in the sample was recorded. This was then extrapolated to an estimate of the total catch. The whole inshore trawl ground was sampled to a depth of 110 m. Net mesh size was either 75 mm stretch mesh (sole-targeted) or 90 mm (hake-targeted).

Contemporary trawl surveys 1985 to 2010

The South Coast Trawl Surveys were conducted by DAFF (Department of Agriculture, Forestry and Fisheries) from 1985 onwards and used until the year 2010 for this analysis. Trawl positions were selected according to a random stratified procedure to cover the inshore and offshore Agulhas Bank. The survey was conducted twice a year in spring and autumn. The vessel used was the *FRV Africana III*. The nets used in the survey had a 75 mm stretch mesh and were lined with 35 mm mesh over the cod-end. Trawl time was standardised at 30 minutes. Surveys were conducted in spring and autumn, although in recent years, the autumn survey has not been conducted. Both seasons were used where trawls were represented in the selected grid blocks as the emphasis in this study is on the long-term temporal trends rather than seasonality of species abundance.

Hypotheses

As a prerequisite to considering potential differences in catch rates, it was necessary to check for uniformity of trawl velocity between the different data sources.

The null hypothesis that there were no significant differences in trawl velocities among surveys was tested with a Kruskal-Wallis test. The non-parametric test was used because variances were not equal among samples, and could not be transformed to achieve homoscedasticity.

A second null hypothesis related to the swept area abundance of each specie: there is no difference in the abundance of chondrichthyan species between periods. This hypothesis was tested separately on each trawl ground. This time a high-frequency of zeros violated the assumption of normality and therefore a parametric, two-factor analysis could not be used (Zar, 2010). Paired tests were used instead, as the differences were normally distributed.

Trawl velocity

The velocity of each trawl was calculated. In the First Gilchrist and Observer Database surveys, the start position, end position, start time and end time were documented. These data were used to calculate the distance covered by each trawl (*D* in km) as follows:

$$\boldsymbol{D} = \left(\left((\boldsymbol{EndLat} - \boldsymbol{StartLat}) \times \mathbf{60}\right)^{\mathbf{2}} + \left((\boldsymbol{EndLon} - \boldsymbol{StartLon}) \times \mathbf{60} \times \cos\left(\frac{\boldsymbol{EndLat}+\boldsymbol{StartLat}}{\mathbf{2}}\right)\right)^{\mathbf{2}}\right)^{\mathbf{0.5}}\right)\mathbf{1.852} \qquad \text{Eq.1}$$

where StartLat and EndLat refer to the latitude in decimal degrees at the position of net-on bottom and haul respectively. Likewise StartLon and EndLon refer to longitude.

Trawl velocity (*V* in km h^{-1}) was calculated using the equation:

$$\boldsymbol{V} = \left(\frac{\boldsymbol{D}}{\boldsymbol{h}}\right) \qquad \text{Eq. 2}$$

where *h* represents trawl duration in hours.

For the Second Gilchrist Survey, trawl distance and trawl time were given in the records, rather than calculated. These estimates were rounded off to the nearest decimal nautical mile. Although associated documentation on these records do not indicate the method of estimation, from the absence of start and end locations, and from the fact that distances were rounded off to the nearest nautical mile, trawl distance was estimated from the ships velocity and the duration of the trawl. The trawl velocity for the Second Gilchrist Survey is therefore regarded as nominal velocity (as opposed to empirical) as it was based on a reading of an analogue instrument measuring speed-over water (and not speed-over ground) at terminal velocity. Such rounding off would also render the velocity estimates inaccurate but there is no reason to believe that a bias exists.

The South Coast Trawl Survey maintained a standard trawl time of 30 minutes and a standard or nominal trawl velocity of 3.5 kt or 6.48 km h^{-1} (Yemane et al. 2008). This estimate is the target or ideal trawl speed over water, measured instantaneously on ships instruments. Start and end times were not given and therefore the trawl velocity for the South Coast Trawl Survey could not be found empirically.

Apart from empirical calculations for the Observer Database survey, shipboard observers independently provided trawl velocity data from the ships bridge which are considered here to represent nominal trawl speed. It is again likely that the estimates represent terminal velocity and do not account for lower velocities associated with net-shooting and net hauling, nor discrepancies between speed over ground and speed over water.

The test of the first null hypothesis was complicated by the fact that trawl velocities were not calculated or recorded in the same way for all surveys. Empirical velocity estimates were available for the First Gilchrist and Observer Database, whereas nominal estimates were available for the Second Gilchrist, Observer Database and South Coast Trawl Surveys. In other words, two sets of estimates are available for the Observer Database survey. The South Coast Trawl Survey could not be included in a test, because a point estimate was provided for all the trawls in that survey. Because sample sizes were vastly unequal and because the Second Gilchrist survey trawl velocity data were not normally distributed, a Kruskal-Wallis test was used to test for differences among the First Gilchrist (empirical), Second Gilchrist (nominal), Observer Database (empirical) and Observer Database (nominal). A post-hoc multiple comparisons test was used to test for differences between surveys (Zar, 2010).

Common trawl grids

The second set of null hypotheses was tested by grouping trawls according to period and trawl ground. The historical surveys (1898 to1904 and 1922 to 1948) were lumped into the Period I and the recent surveys and observer data (1985 to 2010 and 2003 to 2006) were lumped into Period II. The comparison also had to correct for geographical effects.

The area covered by the surveys were not identical, but did include substantial overlap. Individual trawls in each survey were plotted in ArcGIS geographical analysis software and were overlaid onto a 5 by 5 minute grid. Only those grid cells with a minimum of 3 trawls per survey were chosen to be included in the analysis. Trawls overlapped in 3 historically important trawl grounds off the South Coast of South Africa: Cape Infanta, Mossel Bay and Algoa Bay.

Swept area abundance indices

The swept area formula used here incorporates trawl width (*W* in m) and haul distance (*D* in km).

Swept Area (*SA* in km^2) was calculated using the equation:

$$\boldsymbol{SA_i = \frac{D_i \times W_i}{1000}} \qquad \text{Eq. 3}$$

Where subscript *i* refers to a particular trawl.

Normally, Swept Area calculations contain a value for vulnerability. Vulnerability (v) is the ratio of the number of fish caught in the net to the number of fish in the path of the net. This is usually a specie-specific number. However, as no study has been done on the catchability of South African fish, no definite value can be assigned here. In the case where no value is known, it is customary to use a value of 0.5, implying the half the fish escape the fishing gear and are not caught (Walsh, 1996).

Density indices (*DI* in fish numbers/km^2) were calculated using the equation:

$$\boldsymbol{DI} = \frac{C_i^s}{SA_i} \qquad \text{Eq. 4}$$

Where C_i^s is the catch in numbers of specie *s* in trawl *i*.

Due to unequal sample sizes between periods and large numbers of null catches for particular species, average ranks were calculated (smallest value being highest density) and a non-parametric test was used to test the effect of *Period* and *TrawlGround* on abundance estimates.

Vulnerability indices

Using the methodology of Musick (1999), a productivity status was determined for the chondrichthyans commonly caught during the surveys. Biological criteria included the values of von Bertalanffy *k*, fecundity (*fec*), age at maturity (T_{mat}), maximum age (T_{max}) and, where available, intrinsic rate of increase (*r*). Although this methodology is partially based on the International Union for the Conservation of Nature (IUCN) red-listing criteria, these were not used. This is due to the fact that it does not take into account many life history parameters that contribute to the vulnerability of a specie and is more difficult to apply to a fishery environment. Levels of productivity are classed as High, Medium, Low or Very Low based on the lowest-scoring criterion (Table 7). In the case of lumped taxa (e.g. *Raja spp.*), a selection of individual species common in the inshore trawl fishery were categorised rather than the lumped taxon. These were plotted against the percentage change in the specie. A detailed description of the methodology can be found in Musick (1999).

The productivity categories were then compared to threshold values of decline defined by Musick (1999), and the percentage change in this study. If declines breached the thresholds (Table 8) set by Musick (1999), the status of the specie will be automatically adjusted to the *vulnerable* category, highlighting that species for further examination by experts and a further possible classification into the more severe categories of *threatened* or *endangered*.

Table 7: Parameter thresholds proposed by Musick (1999). The lowest parameter is the one that is assigned to the specie. possible parameters are the population intrinsic rate of increase (r, per year, where possible), growth (van Bertalanfy k), fecundity (Fec, per year), age at maturity (Tmat) and maximum possible age (Tmax).

Parameter	high	medium	low	very low
r (yr^{-1})	> 0.50	0.16-0.50	0.05-0.15	< 0.05
von Bertalanfy k	> 0.30	0.16-0.30	0.05-0.15	<0.05
Fec (yr^{-1})	> 10^4	10^2-10^3	10^1<10^2	<10^1
Tmat (years)	< 1	2-4	5-10	>10
Tmax (years)	1-3	4-10	11-30	>30

Table 8: Thresholds suggested by Musick (1999) based on the decline of the population. A species breaching the threshold appropriate to its productivity index is classified as "vulnerable", and highlighted for further research and conservation measures. The decline must take place over the longer of ten years or three generations.

Productivity	Threshold of decline
high	0.99
medium	0.95
low	0.85
very low	0.7

Results

Trawl velocity

The First Gilchrist Survey showed very low empirically calculated trawl velocities, ranging from 1 km h^{-1} to 7.46 km h^{-1} (Figure 18). In the Second Gilchrist Survey, nominal trawl velocities were between 3.08 and 10.03 km h^{-1}. For the Observer Database, empirical and nominal estimates were available. Empirical trawl velocity ranged from 1 km h^{-1} to 6.8 km h^{-1}, whereas nominal velocities ranged from 4.9 to 8.4 km h-1. The median for the nominal Observer Database estimate was 42.9%

greater than the median for the empirical Observer Database estimates. There was significant difference in trawl velocities among all surveys ($p<0.001$).

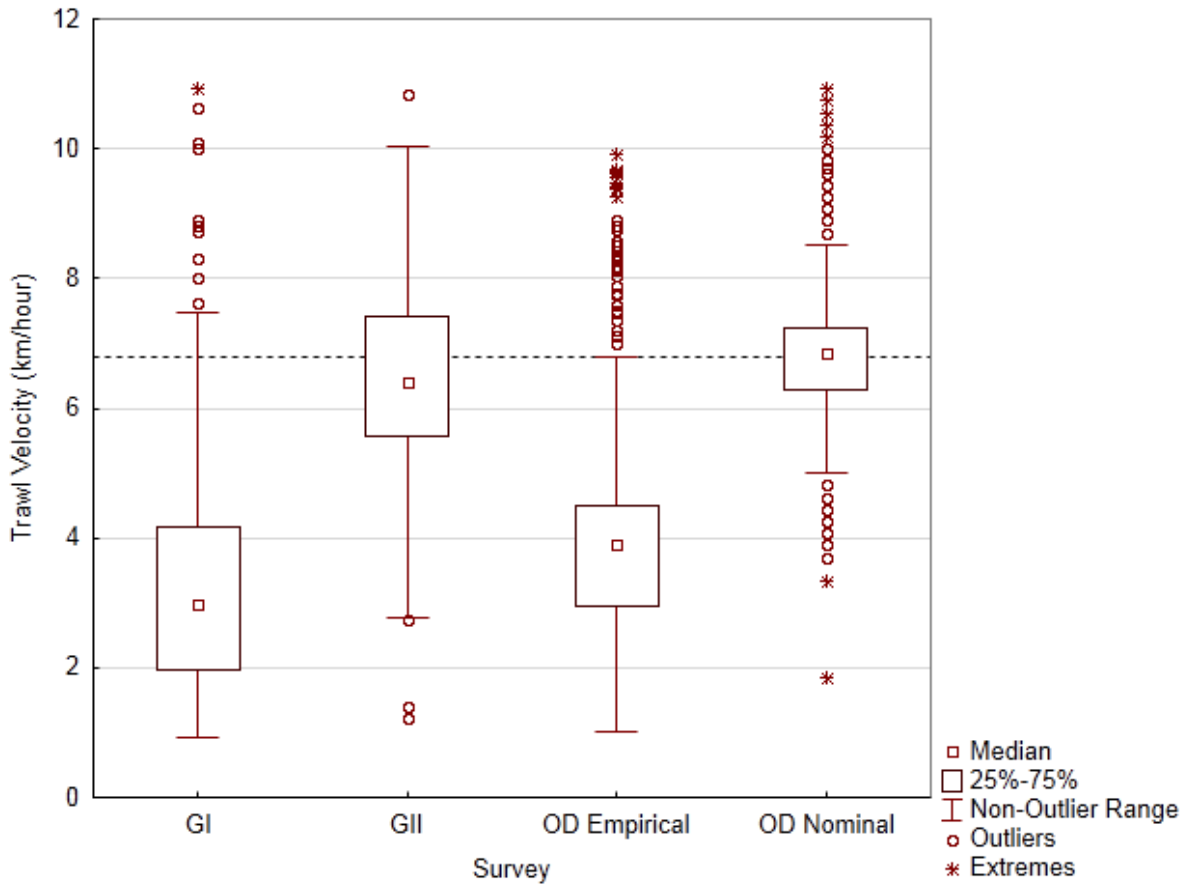


Figure 18: Range of trawl velocities in the surveys. Two values for the Observer Database are given, one nominal and read from the ships instruments and one empirically calculated using trawl start an end coordinates. First Gilchrist surveys are empirical, but the Second Gilchrist survey values are nominal. South Coast Trawl Survey velocity was estimated to be a constant of 6.8 km h^{-1} (3.5 kt), and is represented by the dashed line.

A multiple comparisons test revealed that all survey trawl velocities were, in fact, significantly different due to the large sample size ($p<0.001$, Table 9). However, the magnitude of the difference between the First Gilchrist and the Second Gilchrist Surveys is similar to that of the difference between the empirically calculated Observer Database trawl velocity and the nominally calculated Observer Database trawl velocity. Hence, the First Gilchrist Survey trawl velocity is directly

comparable with the Observer Database empirical trawl velocity and the Second Gilchrist trawl velocity is directly comparable with the Observer Database nominal trawl velocity.

In essence, readings from the ships instruments are not an accurate representation of actual trawl velocity as they obtain the reading as velocity over water, taking current and drift into account. The velocity that the ship is actually trawling at is calculated empirically, and is what ultimately influences actual swept area. Thus, although a nominal reading states that a ship is trawling at, for example, 6.8 km h^{-1}, the ship is actually only trawling at 4 km h^{-1}.

Table 9: The results of a post-hoc Multiple comparison following a Kruskal-Wallis test of nominal and empirically calculated trawl velocities are given. SE= standard error, crit= critical values for the q distribution corresponding to Multiple comparisons (Tukey) test for unequal sample sizes, p= significance. GI= First Gilchrist Survey; GII= Second Gilchrist Survey; OD= Observer Database

Comparison between trawl velocities				SE	q test statistic	crit	p
GI		**OD Nominal**					
	2445.0		3422.8	81.51	11.995	2.639	<0.001
GI		**GII**					
	2445.0		5061.2	95.65	27.37942	2.639	<0.001
GI		**OD Empirical**					
	2445.0		1958.5	81.51	5.968826	2.639	<0.001
GII		**OD Nominal**					
	5061.2		3422.8	71.05	23.06038	2.639	<0.001
GII		**OD Empirical**					
	5061.2		1958.5	71.05	43.67051	2.639	<0.001

The South Coast Trawl Survey had a nominal trawl velocity of 6.482 km h^{-1} which is in agreement with the other median estimates of 6.8 km h^{-1} (Observer Database nominal) and 6.4 km h^{-1} (Second Gilchrist empirical). These comparisons suggest very little, if any, difference in trawl velocity among the surveys. Although the null hypothesis is rejected, the differences are explained by the method of measurement, rather than the actual differences in velocity. This reflects in the significance of the

multiple comparisons test, with significance being caused by the large sample size, not actual differences.

Comparison of swept area surveys between periods 1898 to 1933 and 1985 to 2010

There were 284 trawls from the historical period and 234 in the recent period in the common grid blocks. Mossel Bay was the ground with the most samples (n=327). Cape Infanta had 177 samples while Algoa Bay only had 14. The following twelve species were analysed: *Callorhinchus capensis*, *Carcharhinus spp.*, *Dasyatidae spp.*, *Galeorhinus galeus*, *Mustelus spp.*, *Myliobatidae spp.*, *Narke capensis*, *Poroderma africanum*, *Raja spp.*, *Rhinobatos spp.*, *Squalus spp.*, and *Torpedo spp*. These were chosen as they were the most common species and contained enough records from each period to justify analysis.

The significance of changes in abundance of species between the two discreet periods was tested by way of a Kruskal-Wallis test due to the non-normal distribution of the data. Of these 12 chondrichthyan species originally included in the analysis, only 7 showed a significant trend of increase or decline (Figure 19 to 25). These were *Callorhinchus capensis*, *Carcharhinus spp.*, *Dasyatidae spp.*, *Narke capensis*, *Raja spp.*, *Squalus spp.*, and *Torpedo spp*.

Callorhinchus capensis had an average density that ranged from 0 to 117.6 fish km^{-2}, *Carcharhinus spp* from 0 to 23.2 fish km^{-2}, Dasyatidae from 0 to 36.9 fish km^{-2}, *Narke spp.* from 0 to 2096 fish km^{-2}, *Raja spp.* from 5.5 to 429.0 fish km^{-2}, *Squalus spp* from 7 to 620.5 fish km^{-2}, and *Torpedo spp.* from 0 to 770.7 fish km^{-2}.

Changes in swept area abundance

Increases

The only increase in swept area density among the chondrichthyan assemblage was that of *Callorhinchus capensis,* as found by Kruskal-Wallis tests. The increase was found to be significant in overall abundance (lumped trawl grounds: $p<0.001$). On the individual trawl grounds, increases in density were found to have occurred on the Cape Infanta ground ($z=3.963$, $p<0.001$) and the Mossel Bay ground ($z=10.74$, $p<0.001$). No significant trend in density was found on the Algoa Bay trawl ground ($p>0.001$).

When the change in density was tested between individual trawl grids by way of a t-test, a significant increase was found ($t=-1.35$, $p=0.0012$).

Decreases

Species shown to have decreased in density followed similar patterns as found in the relative abundance (Chapter 2). Overall declines in density were found in *Carcharhinus spp*, Dasyatidae, *Narke capensis*, *Raja spp.*, *Squlaus megalops* and *Torpedo spp*. (all species: $p<0.001$).

On the Cape Infanta trawl ground, significant decreases in fish density were found in *Carcharhinus spp* ($z=-1.1024$, $p=0.001$), Dasyatidae ($z=0.11$, $p<0.001$), *Narke capensis (*$z=-7.84$), *Raja spp.* ($z=-8.066$, $p<0.001$), *Squalus megalops (*$z=1.874$, $p<0.001$) and *Torpedo spp* ($z=-0.42$, $p<0.001$).

On the Mossel Bay ground, significant declines were found in the density of *Carcharhinus spp* ($z=-4.803$, $p=0.001$), Dasyatidae ($z=-5.14$, $p=0.001$), *Narke capensis* ($z=-6.11$, $p<0.001$), *Raja spp (*$z=-14.349$, $p<0.001$), *Squalus megalops* ($z=-11.12$, $p<0.001$) and *Torpedo spp* ($z=-7.559$, $p<0.001$).

However, no significant decline in density was found on the Algoa Bay ground in any of the species ($p>0.001$), nor were changes over time on individual trawl grids ($p>0.001$) for these species.

Most densities were characterised by large amounts of 0 catches. This brought down the medians to lower levels, and caused the spread of high catches to form extensive numbers of large density outliers and extremes.

Changes in density on the individual trawl grounds may be seen in Figures 19-25.

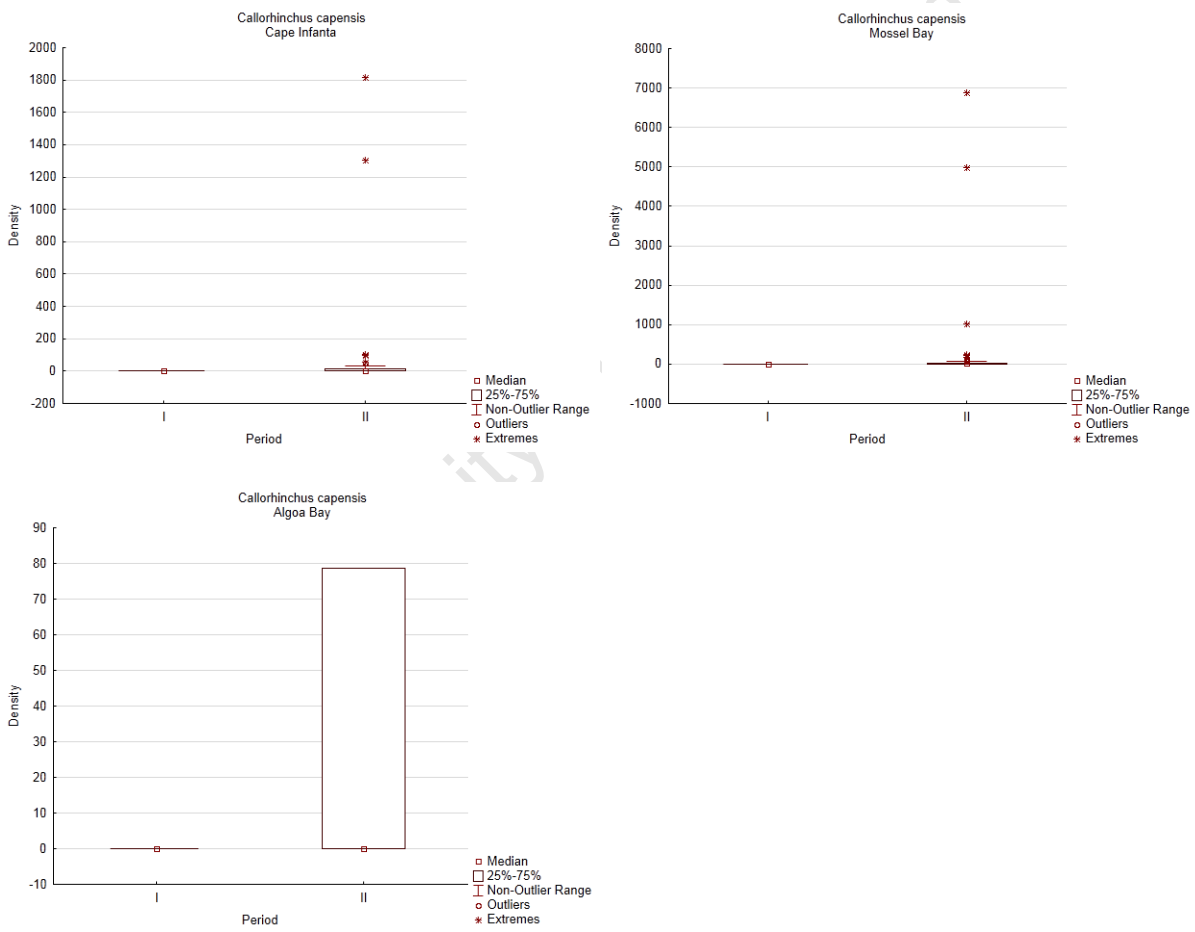


Figure 19 *Callorhinchus capensis* density over two time periods (I=historical, II=recent) and three trawl grounds. Density is in Fish km^{-2}, Standard Error in parentheses.

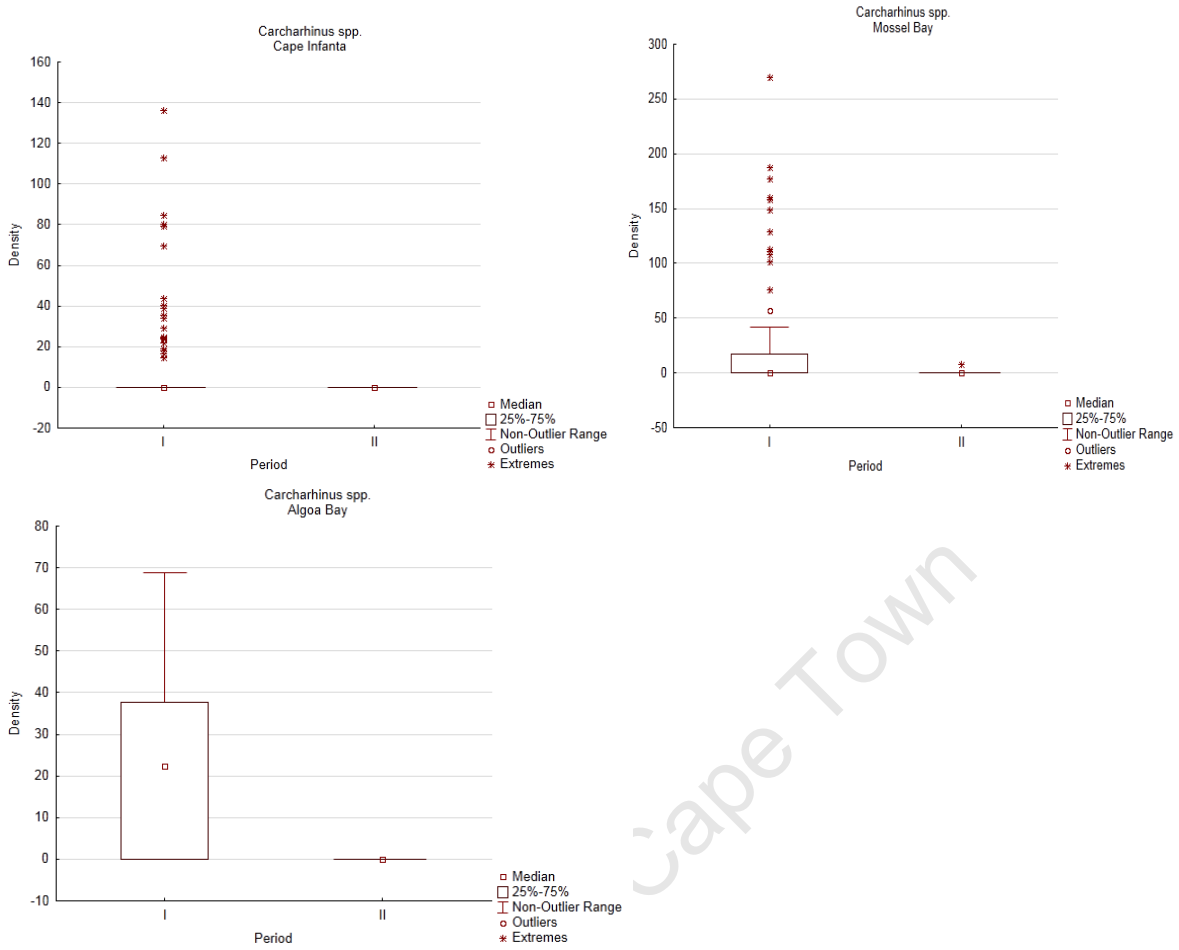


Figure 20: *Carcharhinus spp*. density over two time periods (I=historical, II=recent) and three trawl grounds. Density is in Fish km^{-2}, Standard Error in parentheses.

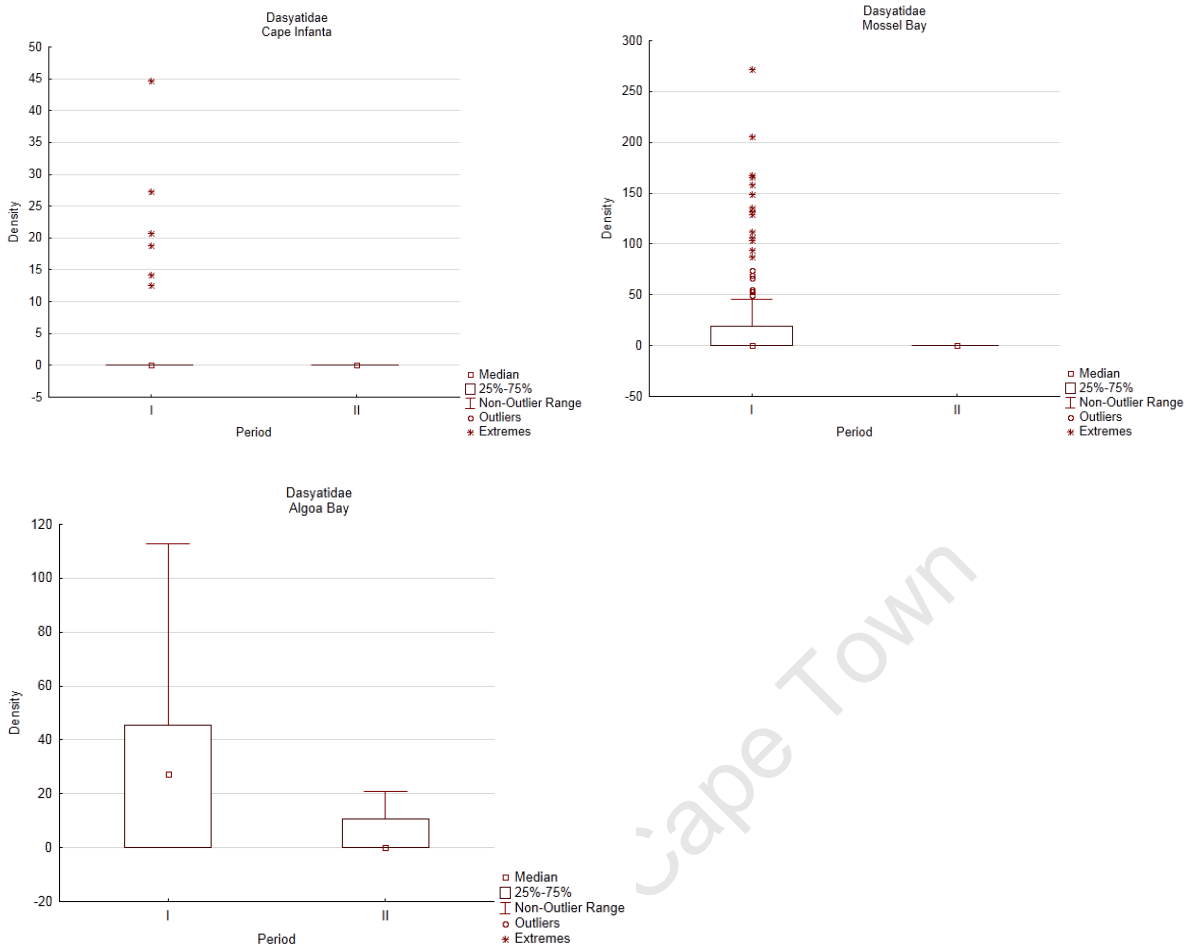


Figure 21: Dasyatidae density over two time periods (I=historical, II=recent) and three trawl grounds. Density is in Fish km^{-2}, Standard Error in parentheses.

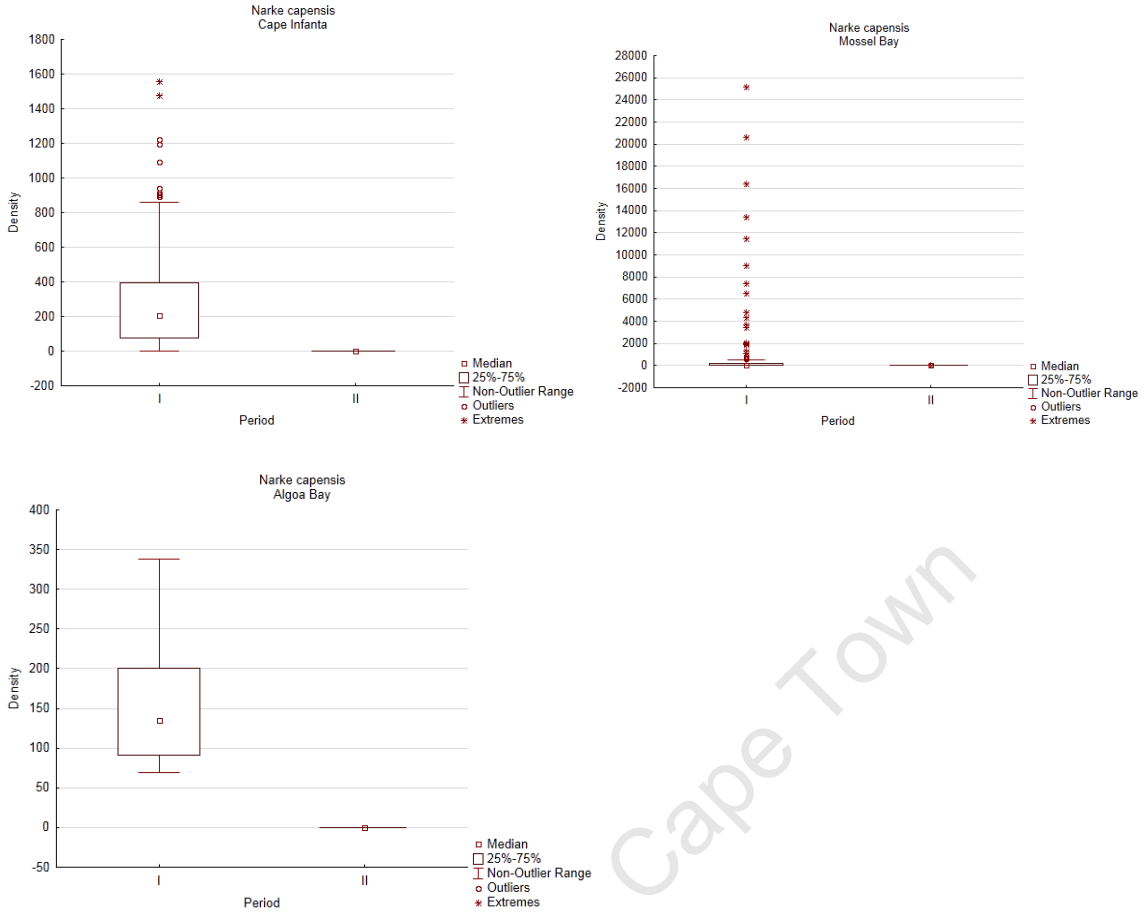


Figure 22: *Narke capensis* density over two time periods (I=historical, II=recent) and three trawl grounds. Density is in Fish km^{-2}, Standard Error in parentheses.

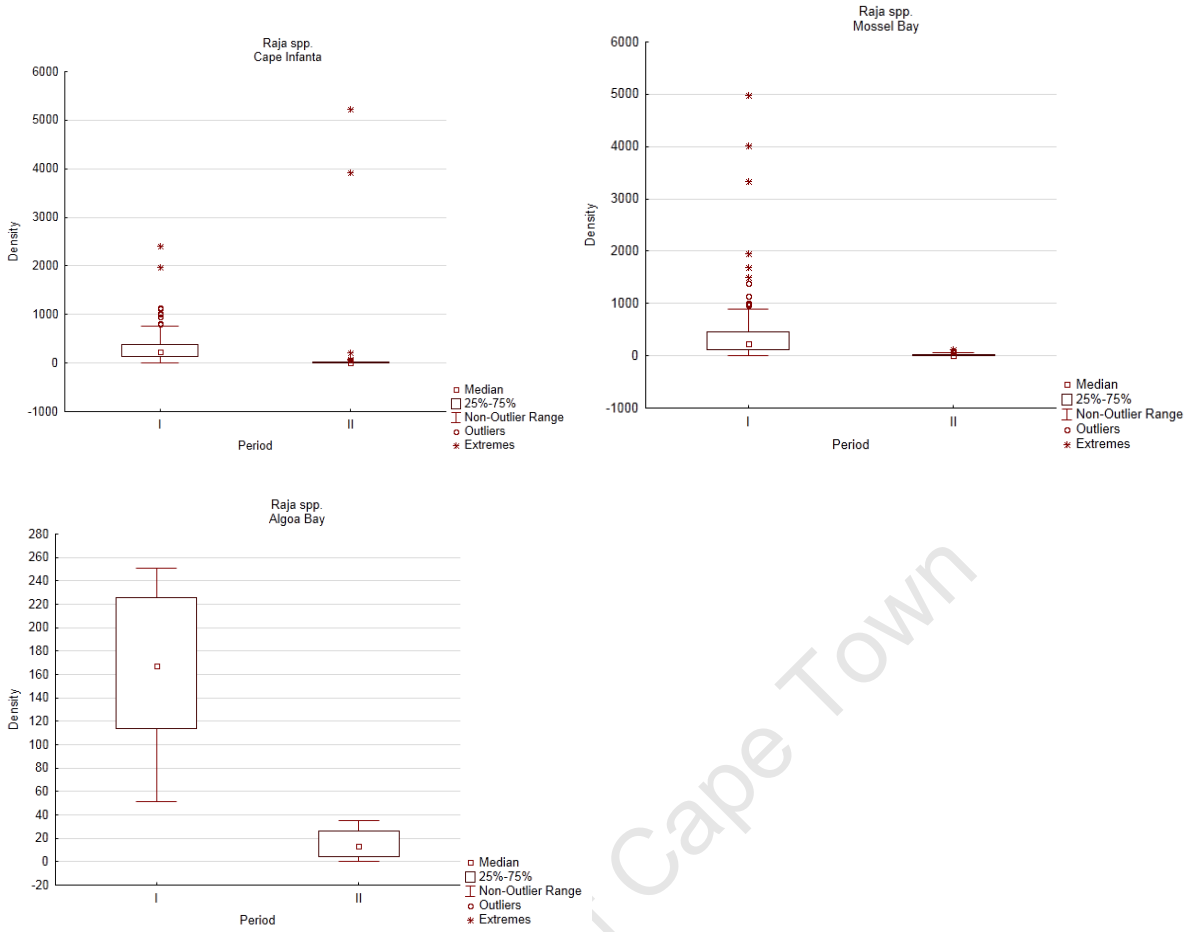


Figure 23: *Raja spp*. density over two time periods (I=historical, II=recent) and three trawl grounds. Density is in Fish km^{-2}, Standard Error in parentheses.

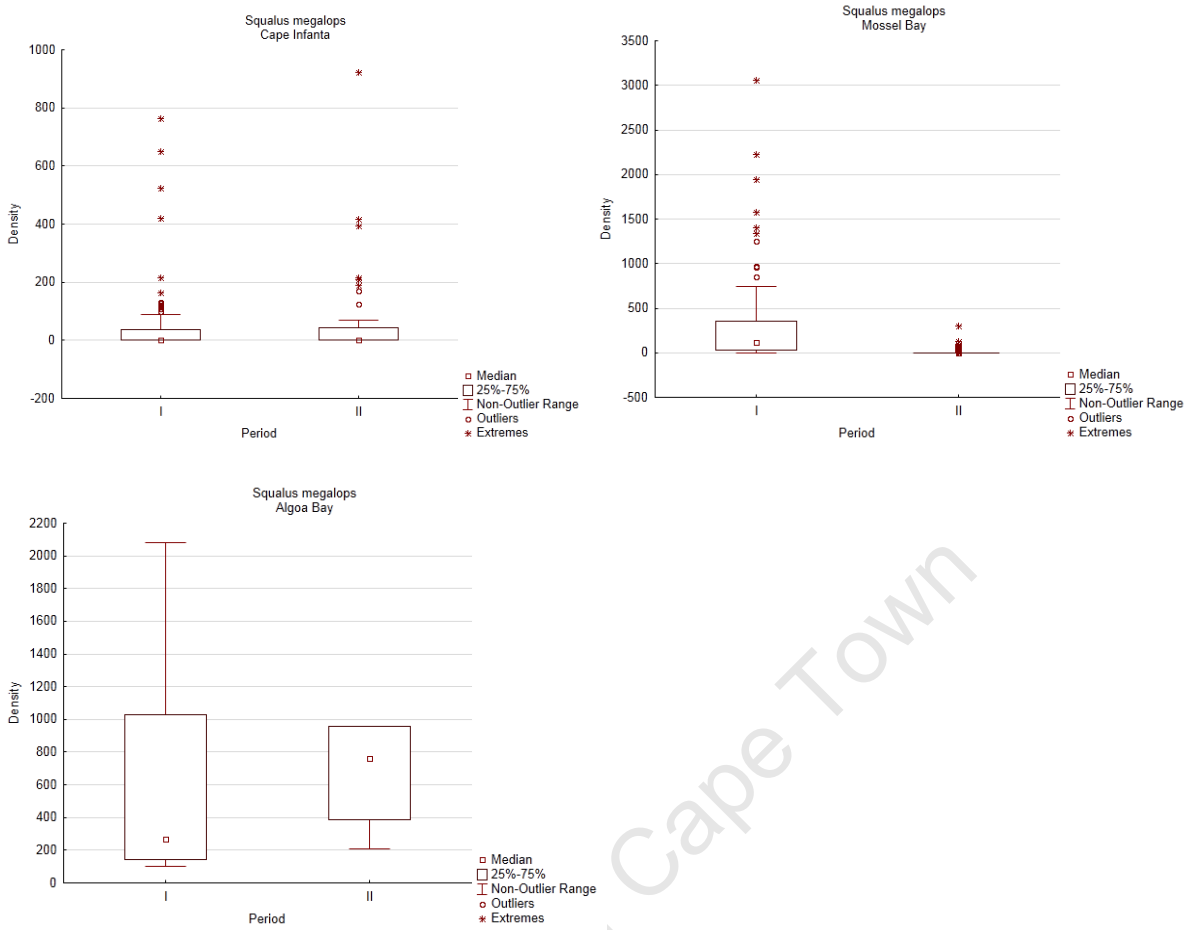


Figure 24: *Squalus megalops* density over two time periods (I=historical, II=recent) and three trawl grounds. Density is in Fish km^{-2}, Standard Error in parentheses.

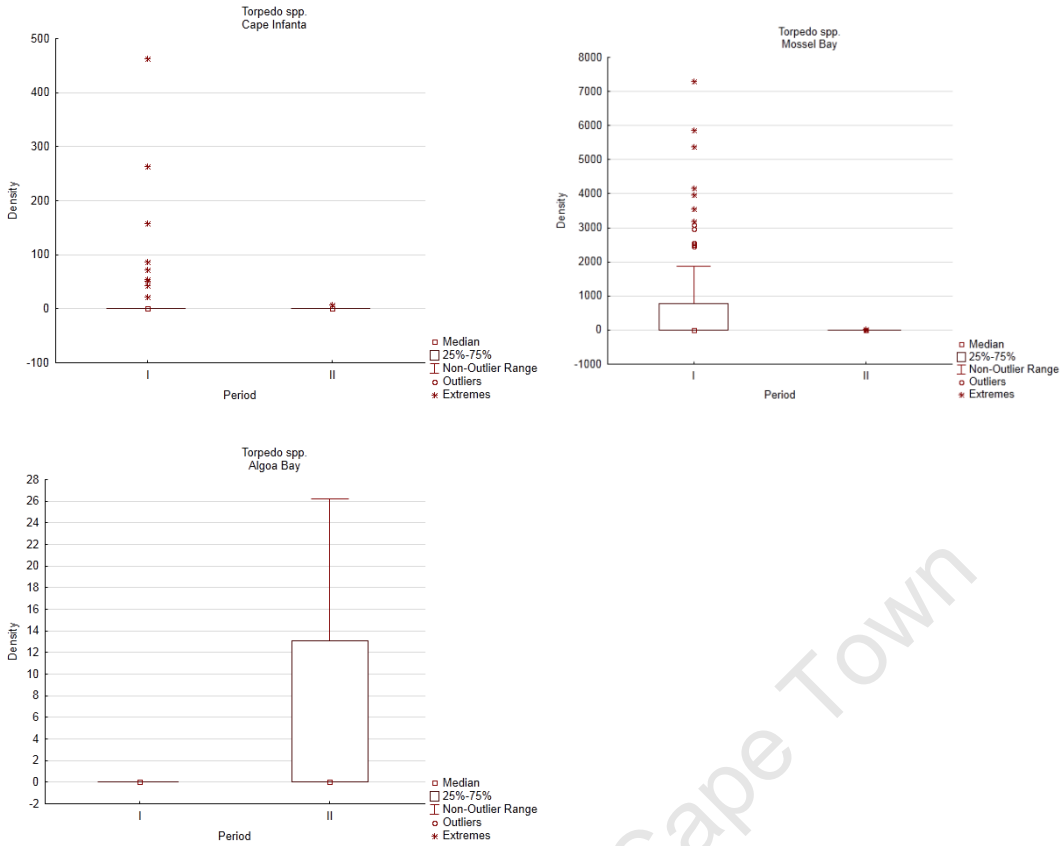


Figure 25: *Torpedo spp.* density over two time periods (I=historical, II=recent) and three trawl grounds. Density is in Fish km^{-2}, Standard Error in parentheses.

Vulnerability indices

Of the four productivity index levels (high, medium, low, very low), chondrichthyans were classified into the two lowest categories only. This includes *Callorhinchus capensis*, which was the only chondrichthyans to show an overall increase in density. Other species showed larger decreases in the range of 78% to 98%. The species and the specific parameter values are displayed in Table 10, and a list of species that were classifies as “vulnerable” are given in Table 11.

Table 10: Common species in the inshore trawl industry analysed according to the criteria set out by Musick (1999). The lowest criteria level is the one assigned to the specie. Species were chosen as those having sufficient data to calculate the significance of declines or increases over two discreet periods separated by 110 years of trawling activity. Parameters are intrinsic rate of increase (r(yr-1)), von Bertalanfy k, number of offspring per year (Fec(yr-1)), age at maturity (Tmat) and maximum possible age (Tmax). The productivity index is decided by the lowest-valued factor. The following references were used in sourcing the data: (Froese & Pauly 2012; Freer & Griffiths 1993a; Freer & Griffiths 1993b; Compagno 1984b; Walter & Ebert 1991; Simpfendorfer et al. 2002; Natanson et al. 1995; Sulikowski et al. 2005; Sulikowski et al. 2003; Ryland & Ajayi 1984; Abdel-Aziz 1992; Michael 1993)

Specie	r (yr-1)	von Bertalanfy k	Fec (yr-1)	Tmat	Tmax	Productivity index
Callorhinchus capensis	-	0.1	<100	3	7	Low
Carcharhinus brachyurus	-	0.04	7	5 to 20	30	very low
Carcharhinus obscurus	-	0.034 to 0.045	3 to 14	>10	30 to 45	very low
Dasyatis pastinaca	-	0.09	4 to 7	-	-	very low
Narke capensis	-	-	<100 assumed	-	-	Low
Dipturus pullopunctata	-	0.05	<100 assumed	-	18 to 14	very low
Rostroraja alba	-	-	55	-	-	Low
Raja clavata	-	0.09-0.14	150	10	24	Low
Raja miraletus	-	0.17-0.19	<100	-	-	Low
Raja straeleni	-	-	<100 assumed	-	-	Low
Squalus megalops	-	-	2	-	-	very low
Squalus mitsukurii	-	-	4	-	-	very low
Torpedo nobiliana	-	-	5 to 32	-	-	Low
Torpedo marmorata	-	-	60	-	-	Low
Mustelus mustelus	-	0.06-0.12	4	6 to 15	24	very low
Myliobatis aquilla	-	-	3 to 7	-	-	very low
Sphyrna zygaena	-	-	20 to 50	-	-	Low
Heptranchias perlo	-	-	9 to 12	-	-	very low
Rhinobatos annulatus	-	0.3	2 to 10	-	7	very low

Table 11: A list of common chondrichthyan species in the inshore trawl industry whose significant change in overall abundance reached or surpassed thresholds set by Musick (1999), placing them in the "vulnerable" category for further analysis. *Callorhinchus capensis*, did not qualify for the vulnerable status as it increased.

Specie	Status
Callorhinchus capensis	-
Carcharhinus brachyurus	Vulnerable
Carcharhinus obscurus	Vulnerable
Dasyatis pastinaca	Vulnerable
Narke capensis	Vulnerable
Dipturus pullopunctata	Vulnerable
Rostroraja alba	Vulnerable
Raja clavata	Vulnerable
Raja miraletus	Vulnerable
Raja straeleni	Vulnerable
Squalus megalops	Vulnerable
Squalus mitsukurii	Vulnerable
Torpedo nobiliana	Vulnerable
Torpedo marmorata	Vulnerable

Discussion

Swept area abundance is used in fisheries stock assessments. It is regarded as a reliable representation of the actual densities of species (Walsh, 1996). Swept area data is usually calculated from scientific fisheries surveys. Its strength arises from the standardised sampling method, random station selection and accurate species identification, which allows comparison over time. On the other hand, a weakness is its potentially poor spatial coverage, due to the utilisation of a single survey vessel (standardised gear and fishing power). However, this may be overcome with long-term observation.

Recently, Leslie (2008) presented abundance indices for common trawl species on the Agulhas Bank. These were calculated from the 23 years of fisheries survey data collected by the *FRV Africana* between 1985 and 2008. This is one of a few studies to use a swept area abundance methodology in this area and one of the only ones to include chondrichthyans. Richardson et al. (2000) used swept area to calculate the abundance of the Izak catshark, Kirchner & Mcallister (2002) used it to estimate

the abundance of Namibian orange roughy *Hoplostethus atlanticus* and Rademeyer et al. (2008) used it to calculate hake abundance.

Trawl velocity

Swept area is dependent on the width of the trawl net and trawl velocity. It was generally assumed that historical trawlers had slower cruising and trawling velocities. To my knowledge, few studies have specifically compared trawl velocities between historical and recent periods. Most comparisons between old and recent fish abundance either re-created the trawls exactly (Greenstreet & Hall, 1996; McHugh et al. 2011), or used statistical methods to standardise for differing catch rates while not directly accounting for trawl velocity (Maunder, 2004).

Nominal velocity was read off the ships' instruments. Nominal values centred around 6.5 km h^{-1} to 7.00 km h^{-1}. In comparison, empirical velocities were calculated using coordinate and time data recorded by the observers. These centred around 3.00 km h^{-1} to 4.5 km h^{-1}. Nominal and empirical values differed significantly due to sample size. In their review of the East Coast trawl fishery, Booth & Hecht (1998) report a nominal velocity of around 2 kt to 3 kt (3.7 km h^{-1} to 5.6 km h^{-1}). It is not stated how velocity was calculated, although based on the results presented here, it was calculated empirically.

Although it may be true that ship's power and cruising velocity was lower in the historical period, this is not necessarily true for trawling velocity. The trawl velocity in the inshore trawl fishery has changed little over the years, as the nominal velocities are comparable between surveys and the empirical velocities are comparable between surveys. The ship actually trawls at the empirically calculated velocity (speed over ground), rather than the nominally recorded velocity (speed over water).

The advantage of greater power is therefore simply the ability to pull larger nets. There is an optimal speed at which to catch fish, but these may differ among targets. It is known that sole (*Austroglossus spp*.) lie flat on the sediment, requiring a slower trawl, whereas hake (*Merluccius capensis*) and silver kob (*Argyrosomus inodorus*), are capable of outswimming a trawl, and will succumb only to higher velocities. Although there was a shift from sole to hake in the early fishery, the evidence of trawl velocity reflecting such a switch is weak. Trawl nets towed at lower velocities run the risk of not being held open if the trawl doors fall over, whereas higher velocities

may cause the net to skim over the top of the substrate, and not catch any fish. The case may be that a historically acceptable balance was found at around 6.8 km h^{-1} (3.5 kt) trawl velocity, at which the trawl doors can hold the net open, yet it is not too fast as to lower catch rates. The lower limit to trawling speed is possibly also set by the need to maintain steerage, particularly in rough seas and crosswinds.

Several possible factors may contribute to a flawed velocity reading. Firstly, a discrepancy is caused by the velocity being calculated over water in the nominal reading and over bottom (ground) in the empirical reading. Speed over water takes current into account. Trawls against the current would register as faster than the ship is actually travelling, while trawls with the current would be registered as slower than the ship is actually travelling. The even distribution of outliers could have resulted from ships trawling both with and against the current. On the other hand, by calculating the velocity using the GPS coordinates, current is excluded and only changes in geographical position are accounted for. This leads to the actual trawl velocity being lower than if measured by an impeller.

In addition, trawl velocity is not likely to be constant over the entire length of the trawl. Coordinates and trawl velocities are noted at the beginning and the end of the trawl tracks. If there are indeed varying trawl velocities between the beginning, middle and end of the trawl track, these would not be recorded. Walsh (1996) stated that speed is usually never constant during a trawl, as this depends on substrate and the resistance it causes to the net. For example, there is a decrease in velocity at the moment when the net hits the bottom and again when it is hauled as the net drag holds the ship back while the winches pull the warps up towards the surface. However, once the gear is in place on the bottom after shooting, the velocity may then be reduced to a more consistent trawling speed.

Finally, nominal records are certainly rounded off, or may simply be reported as the maximum or target velocity. These biases would depend on the individual observer or skipper. All these factors might add uncertainty to the data as records are obviously less accurate.

When attempting to account for environmental variables such as current, the velocity through water will be more accurate. Calculating abundance indices must be done using distance (velocity) over ground, as this is the actual distance that the net has been towed.

When calculating abundances, the second Gilchrist database only recorded trawl time and distance, but not trawl-end coordinates. This means that the trawl track calculated was through water, and not over ground. As a consequence, swept area was possibly greater than calculated, leading to an underestimation of abundance in this survey.

Swept Area density

Changes in swept area density of selected Chondrichthyan species mirror those trends found in the relative abundance. Six out of 7 Chondrichthyan species or specie groups were found to have declined significantly over the period. Declines were found in the genus *Carcharhinus*, *Narke*, *Raja*, *Squalus*, *Torpedo* and the family Dasyatidae. Due to lumping of species and some large gaps between surveys, no continuous time series at specie level could be constructed.

These findings are generally consistent with those of Leslie (2008), who presented the absolute abundance (biomass) of bycatch species found in the demersal trawl fishery. It could be assumed that the trends will hold true even through the missing years in the historical data, as the amount of fishing effort on the inshore Agulhas Bank showed no respite during the course of the century. Disadvantages of comparisons are that Leslie calculated overall biomass abundance (West and South Coasts), rather than focussing on separate grounds and the comparatively short time period that his study covers.

The only deviation to the trends reported by Leslie (2008) was found on the Algoa Bay ground in *Squalus megalops* and *Torpedo spp*. The confinement of such a break in the trends to one ground may have one of two origins: firstly, it may be a local phenomenon restricted to *Squalus megalops* and *Torpedo spp*. on the Algoa Bay ground; or secondly, it may be an artefact of the small sample size. Although the median for the recent period is 0 for the abundance of *Torpedo spp.*, there seems to be an increase in the frequency of capture of these species in the recent period.

All other species follow the same trend over all three trawl grounds as found in the relative abundance, independent of sample size. Thus, it could be expected that *S. megalops* should do the same. From the analysis in Chapter 2 it was clear that there were significant differences among trawl grids, and it follows that local deviations in trends are possible. A decrease in either predatory fish or a competitive release may explain the increase on the ground. In essence, this speaks for the hypothesis that a local environmental effect or a secondary effect of trawling has benefited the species there.

On the other hand, despite a small sample size of only 14 trawls spread over the two periods, none of the other species show this sort of deviation from the trends exhibited elsewhere. In the light of the preceding analysis in Chapter 2, and reflecting the results of the other species and results from this chapter, I suspect that the Algoa Bay abundance for *Squalus megalops* is lower in the recent

period than indicated in this analysis and that this deviation may have been caused by a small sample size.

As for the increase in *Torpedo spp*. density, this may be the misidentification of *Narke capensis* in the recent period. From preceding analysis in Chapter 2, it is clear that *Torpedo* is not a common specie, but occurs in greater abundance along the South Coast and is rarer on the East Coast, whereas *Narke capensis* is more present on the eastern grounds. The chance capture of individuals, while possible, seems less likely. Therefore, the misidentification of *Narke capensis* is most likely, for example in the observer database, where no *N. capensis* was recorded in the grid blocks analysed, however, the specie was recorded correctly in other observer samples. This may suggest confusion of the two electric ray species.

Should a similar study to this one be conducted again, it would perhaps be possible to find a greater overlap of historical and recent data. If it were possible to thereby increase the sample size when calculating absolute abundance, the trends on the Algoa Bay ground may become clearer.

Increases

Callorhinchus capensis

Callorhinchus capensis was the only Chondrichthyan to have shown an increase. In his analysis, Leslie (2008) shows that abundance rises from an initial value of just under 10,000 kg nm^{-2} in 1986 to a peak of 40,000 kg nm^{-2} in 1993. After declining sharply again, abundance recovered and continued to increase from 1995 onwards to a recent value of just over 30,000 kg nm^{-2} in 2008.

In the historical trawls, no *C. capensis* were present in the areas analysed, despite extensive sampling. However, *C. capensis* is present in the remainder of the historical trawls excluded from this analysis, so trawl speed was adequately fast in order for them to be captured and there could be no confusing the identity of this unusual specie. It is possible that on the micro-scale (*GridBlock*), the habitat was not suitable for *C. capensis* during the historical surveys and only later became habitable. Climatic change may have brought about an eastward shift in this species' distribution, as it did for rock lobster (Cockcroft et al. 2008), kelp (Bolton et al. 2012), sardines and anchovies (Roy et al. 2007; Coetzee et al. 2008). Furthermore, secondary effects may have contributed to the

increase, such as a release from competition by skates, which have decreased. The increase certainly indicates that something in the system has changed to make this one of the few cases of increasing chondrichthyan abundances. Generally, increases in chondrichthyan abundance happen most when a predator-release reaction happens (Myers et al. 2007; Shepherd & Myers, 2005).

C. capensis was classified with a productivity index of "Low". Compared to other chondrichthyans, however, fecundity is high and may play a role in the increase found in the grid blocks analysed.

This is especially interesting since the Australian stock of a related specie, *Callorhinchus milii*, collapsed following overfishing in the 1980s, and is currently being rebuilt (Stevens et al. 2000). This was, however, due to exploitation in a directed fishery, but proves that this is a special case of relative stability on the South Coast. As to the further classification of *C. capensis* in the trawl industry according to Musick (1999), the methodology deals only with declines in abundance, not general changes. In this case of a chondrichthyan increasing, it would be appropriate for *C. capensis* to remain in the "least concern" category, despite its "low" productivity.

Decreases

Carcharhinus spp.

Although several species of *Carcharhinus* are found in the waters surrounding South Africa, little distinction is made in some of the records in the databases as identification of individual species can be difficult.

No abundance indices were calculated by Leslie (2008) for this group of sharks. They are a rare bycatch in the trawl fisheries as they have a more pelagic life strategy and any capture is purely incidental. However, sharks of the genus *Carcharhinus* have shown dramatic declines worldwide. For example Dudley & Simpfendorfer (2006) show catch per unit effort trends in the protective gillnets off KwaZulu-Natal in South Africa for several species of *Carcharhinus*, whereas Camhi et al. (2009) classifies a selection of vulnerable species around the world.

These declining trends coincide with those trends found in this study. Unfortunately, the lack of specie-level identification cannot show potential increases masked by lumping (Dulvy et al. 2000). In

light of the overwhelming literature on the decline of Carcharhinid sharks around the world, I believe it is safe to say that the specie trends should mirror those found for the lumped genus.

Categorisation according to Musick (1999) placed species of the genus *Carcharhinus* into a "very low" productivity category and classified the two analysed species as "vulnerable". These sharks possess generally slow reproduction rate and longevity. This makes them especially vulnerable to exploitation by fisheries, where they are caught as bycatch, yet increasingly as targets due to valuable body parts (Clarke et al. 2006).

Dasyatidae spp

Little distinction was made between individual species of stingrays. However, the declining trend exhibited by the lumped category does corroborate those specie-specific trends found by Leslie (2008). Only *Gymnura natalensis* shows a more erratic trend in that study, but has lower catches than other Dasyatids, most likely due to its inshore and estuarine habitat (Heemstra & Smith, 2002). *Myliobatis aquilla* also shows an erratic trend. This is a schooling specie, and it may indicate the annual sampling in areas with a seasonally high density of rays, rather than an Agulhas Bank-wide trend.

However, Dasyatis pastinaca did have sufficient data available to classify it as having a "very low" productivity, with a relatively low fecundity (4 to 7 pups per year). In addition, and not included in the Musick methodology, is its relatively large body size, making it susceptible to trawling (Heemstra & Smith, 2002).

Narke capensis

Although only present in all records at low levels, *Narke capensis* has shown a significant decline. Due to the infrequent catches it is unclear whether or not there has been a declining trend found in the more recent time set. The specie trend exhibited in Leslie (2008) is unclear, as extremely high catches in 1993 mask the overall trend.

The present study clearly finds a significantly declining trend in abundance from historical levels. This is emphasised by the assigned productivity index of "very low" and the "Vulnerable" status. A lack of biological information hampers further assessment for this fish, and it is classed as "data deficient" by the IUCN (Camhi et al. 2009).

Raja spp.

Leslie (2008) also shows declining trends for the lumped skate category. It is noteworthy that the declining trend masks small increases in abundance when analysed at the specie level. Increases in the recent times were found in *Cruriraja*, *Raja pullopunctata* and *R. wallecei* by Leslie (2008). This leads to the suspicion that these trends have been continued on from historical times.

Vulnerability indices were not calculated for a lumped group of Raja, but rather the most common species were chosen, based on Leslie's (2008) abundance indices. With the exception of *Dipturus pullopunctata*, all species grouped in the "Low productivity" category. Still, all skate species were classed as being "vulnerable".

Squalus spp.

Of the two species of spiny dogfish found on the Agulhas Bank, both have shown declining trends in Leslie (2008), although at different rates. *Squalus megalops* shows an increasing trend of abundance until approximately 1995, after which the trend stabilises before declining from around 2000 onwards until present. *Squalus mitsukurii*, on the other hand, shows a sharp decline from the beginning of the trawl surveys until around 1992, when the trend increases to a high in 1995, before falling again to low levels sustained until the present. Large catches of these sharks may be due to the schooling behaviour they exhibit. *S. megalops* inhabits the inshore waters, whereas *S. mitsukurii* is a deeper-water specie.

The lumped group of *Squalus* was split into the two species for the calculation of vulnerability indices, but the results were found to be identical in the "Very Low" category and the declines were sufficient to class the genus *Squalus* as "vulnerable".

Torpedo spp.

Electric rays of the genus *Torpedo* have also shown significant declines over time. The relatively low abundances in my study indicate that species of *Torpedo*, like *Narke*, were never overly abundant. Leslie (2008) shows that today, these rays maintain a low abundance. However, even at these relatively low levels, a significant decline was detected.

The genus *Torpedo* also was classed as having "low" productivity, despite being relatively fecund. However, a paucity of further biological information and the stark declines lead *Torpedo* to being classed as "vulberable".

Vulnerability indices

As the understanding of ecosystem affects have developed, and changes in abundance of non-target species have been researched, a need has developed to estimate the response of species to exploitation (Musick 1999; Nilsson & Grelsson, 1995). Several methods of this process have been developed, each with their strengths and weaknesses (IUCN, 2001; Musick, 1999; Rohlf, 1991).

Other methods besides those of Musick (1999) of classifying species' declines have been implemented. One of the most common is the Red List compiled by the International Union for the Conservation of Nature (IUCN). Species are classified by a combination of their population decline, distribution, habitat loss, existing measures of conservation, existing- and potentially negative impacts and biological factors such as reproductive capacity (IUCN, 2001).

The strengths of the IUCN method of classification are that it indicates which species are in need of conservation measures immediately based mainly on ecological and habitat parameters. This method is best when applied to terrestrial and freshwater ecosystems. Marine ecosystems are more dynamic and thus boundaries are more difficult to define. In addition, population counts and densities are more difficult to quantify in a marine environment. Despite these shortfalls, the IUCN Redlist is the first attempt at an international standard to quantify the risk of extinction for individual species. However, this system was originally designed to conduct global assessments. The trend of

assessing species has instead turned towards a regional and national level. The assessment methods were therefore updated and now include regional assessments (IUCN, 2001).

Some countries have their own protective legislature and methods of classifying at-risk species. The USA has the Endangered Species Act. Despite controversy and gaps in the classification system (Rohlf, 1991), this has been used in the USA as the standard classification scheme, although fisheries now use the methodology developed by Musick (1999).

Australia uses a three-tiered system to define marine species of conservation concern (Braccini et al. 2006). Level 1 assessment is based on a quantitative analysis of fishery activities impacting the specie and based on existing expert knowledge. Level 2 is based on the biological productivity of the specie based on reproductive rates or natural mortality, conducted in each fishery sector, and looks at the potential susceptibility and mortality caused by the fishing. Level 3 is a quantitative and data-intensive analysis using models that include biomass, abundance, fishing effort and catch data.

An analysis of vulnerability was possible in Australian waters for *Squalus megalops* (Braccini et al. 2006). Level one analysis found that the otter-trawl, Danish seine, shark gillnet and longline fisheries are having a large impact on the population. Low reproductive capabilities and high mortality in the capture fisheries classed *S. megalops* at a high risk at Level 2. At level 3, a low population rebound potential was found in both a worst-case scenario model and a more optimistic model.

All this contributed to classing *Squalus megalops* at a high susceptibility to fishing and population decline. This finding supports the trends and vulnerability categorisation found for *Squalus megalops* in my study.

The vulnerability indices calculated according to Musick (1999) matched what was expected of the selected chondrichthyans. Low fecundity and slow maturation rates placed them consecutively in two categories of low productivity. There were too few species and thus too few vulnerability categories to conduct a directly comparative analysis with, for example, teleost fish or related species as in Dulvy & Reynolds (2002). Such a procedure would unequivocally test chondrichthyan susceptibility to trawling pressure. However, all analysed chondrichthyans were grouped as “vulnerable” according to the methodology by (Musick, 1999), underlining the need for a closer look at the status of these cartilaginous fish.

One disadvantage of these vulnerability classification methodologies is that they deal exclusively with decreases in abundance. The main advantage of this method, however, is that it is applicable to species that are under exploitation pressure. By using biological data only, Musick (1999) avoids the caveat in the IUCN methodology, where the main variable to categorisation is changes in habitat and population size (IUCN, 2001).

The other alternative method proposed by Dulvy & Reynolds (2002), who stated that a simple size-class distinction should be sufficient to categorise species at risk, would not have worked in this case. *Callorhinchus capensis* can attain a comparatively large size compared to *Squalus megalops*. Despite this, *Callorhinchus capensis* increased whereas *Squalus* decreased.

Therefore, the prediction of what a species' response will be to fishing pressure (both direct and indirect effects), is not as easy as sometimes stated. In the end, categorisation techniques are useful only to highlight species in danger of being overexploited or negatively affected by fisheries (or other environmental disturbance), and not a certain predictor of trends.

CHAPTER 4: IMPLICATIONS OF THE RESULTS AND A DISCUSSION OF THE EXPLOITABILITY OF CHONDRICHTHYANS

Up until the mid 1970's, fisheries assessment was an exclusively single-specie paradigm, usually based on landings data (Hall et al. 2000). Only when several important fish stocks such as North Atlantic cod (*Gadus morhua*) and Peruvian anchovetta (*Engraulis ringens*) collapsed, did scientists realise that fisheries independent data are needed to provide unbiased estimates of stock abundance (Jennings et al. 2006). The provision of these data are now the purpose of surveys.

Fisheries policies often require the regular assessment and interpretation of survey data. Survey datasets usually stem from scientific survey activity within the past twenty to fifty years. Industrial trawling has been conducted for at least one hundred years, but the first 50 to 80 years typically lack survey data. Truly historical datasets from times before industrialised fishing activity and representing baseline abundance values, are exceptionally rare (Rijnsdorp et al. 1996). Such data would allow scientists to describe and quantify an un-impacted ecosystem.

Historical data of such antiquity formed the basis of the comparative analysis in this study. It was collected during surveys commencing in 1898 and was here compared to contemporary surveys and observer data ranging from the 1980's to the present. I looked at the changes in trends of bycatch species found in the inshore demersal trawl fishery on the Agulhas Bank, South Africa. Special interest was shown in the trends exhibited by the chondrichthyans (sharks, skates, rays and chimaeras). Generally, chondrichthyan productivity cannot sustain higher rates of exploitation often applied to the harvest of teleost species. The low productivity is due to their slow growth processes, late maturation, low fecundity and trans-boundary distribution. In South Africa, only two species (*Carcharhinus carcharias* and *Carcharhias taurus*) of the estimated 59 chondrichthyan species have protective legislation at the moment. Of the remaining 57, a large proportion is found in the bycatch assemblage of the inshore trawl fishery.

The historical data used in this analysis was of good quality and consistency. There were only two deficits in the quality of the records: 1) changing recording protocols and 2) inconsistent size-classes recorded for some species.

The change in recording led to the exclusion of several species that now constitute an important part of the bycatch assemblage. During the surveys, it was not envisioned that hake would eventually

become the main target specie, so initially the recording covered all species equally, including hake (as a bycatch specie), and sole (as a target specie). The recording of the entire catch assemblage was only re-instated with the advent of ecosystem-management models in the mid 1990's.

In this study, the historical data was used to most of its potential. The shortcomings listed above did not affect the outcome of this study. Future studies with perhaps different focal points (for example focussing on economically important species), may be able to use the length frequencies for those species. The large gaps in time may be able to be bridged using statistical extrapolation techniques such as bootstrapping. However, two distinct time periods still allowed a good comparison without having a complete time series. The recording of the spectra are not continuous through the stations comprising the surveys so it is uncertain if there is sufficient information to perform this kind of analysis.

I believe that the trawl grounds where spatial overlap between historical and contemporary surveys has occurred have been sufficiently analysed in this study. Other areas covered by the historical surveys for which there is no recent trawling record may be of interest, especially if they lie outside of the three trawl grounds analysed here. The re-creation of trawls using similar speed and gear should provide and interesting comparison, should funding be secured (Rijnsdorp et al. 1996).

Multivariate techniques were used to discern trends in the catch composition and univariate techniques were used to calculate absolute density over time on three historically important trawl grounds on the Agulhas Bank.

The findings of this analysis show an increase in relative abundance of most teleosts. Species showing increases are now dominant in the catch of the inshore trawl industry, and include horse mackerel (*Trachurus capensis*), hake (*Merluccius capensis*) and gurnards (*Chelidonychthyes spp*). Increases in the chondrichthyan relative abundance were restricted to the St. Joseph shark (*Callorhinchus capensis*). Decreases in relative abundance were found in species of generally large size and traditional target preference. These included silver kob (*Argyrosomus inodorus*), sole (*Austroglosssus pectoralis*), the sea breams (Sparidae) and additionally all remaining chondrichthyan species.

There were significant changes over time in swept area density indices for seven species. Declines were found in *Carcharhinus spp*, *Dasyatidae*, *Narke capensis*, *Raja spp*, *Squalus spp*, and *Torpedo spp*. The only increase was found in *Callorhinchus capensis*. These trends conform to those analysed by (Leslie, 2008), suggesting that these trends have been continuous from since shortly after the

opening of the fishery to present. Using the threat scheme developed by the American Fisheries Society (Musick, 1999), all chondrichthyans analysed were classed in the “Low” or “Very Low” productivity category. This classification matches the trends one would expect to see. Only the *C. capensis* population on the South Coast has other influencing factors which allowed an increase in absolute density despite the low biological productivity.

These results conform to what was expected for the trawl grounds based on what has been found in comparable studies investigating the long-term trends of benthic, trawled habitats in temperate shelf waters (McHugh et al. 2011; Rice & Gislason, 1996; Yemane et al. 2004; Yemane et al. 2008). However, the number of species that have been classified as “vulnerable” is alarming. As some lumping and transferring of declining trends was necessary to complete this analysis, an in-depth look is imperative in order to prevent a further decline.

Causes of declines and increases

Several studies have been conducted comparing historical data from the early 1900’s with recent data. They focus on the northern hemisphere; most notably European waters and the North Sea, where bottom trawling was first attempted and has been conducted since. Often, the focus of studies lies in the examination of the catch composition as a proxy for the ecosystem rather than investigating the absolute abundance trends. This follows the recent focus on ecosystem management. Our knowledge of the effects of trawling on benthic temperate shelf systems has thereby been improved, and the causes for declines and increases in relative abundance have been discussed at length.

Most recently, McHugh et al. (2011), were able to re-create the trawls undertaken in the early 1900’s in the western English Channel. They were able to directly compare the present conditions of study areas around Plymouth, United Kingdom, with historical conditions. Heath & Speirs (2011), analysed temporal changes using a Large Fish Indicator in the fjord-like Firth of Clyde, Scotland, from 1962 until present while Greenstreet & Hall (1996), concentrated on the specie assemblage structure.

The results of these studies vary slightly. McHugh et al. (2011) found significant changes in the specie assemblage over time, while the total number of species remained stable. While size

structure changes were insignificant in the flatfish and the roundfish components of the assemblage, it was not in the elasmobranch component, which also saw a significant change in relative abundance. Especially the skates and rays decreased, whereas the catshark *Scyliorhinus canicula* increased. This confirms what was found in Greenstreet & Hall (1996), who found that changes in relative abundance were caused by species targeted by the fishery, with changes in absolute abundance being subtle yet significant shifts in a few, rare species. More drastic changes were found in Heath & Speirs (2011). Historically, 95% of the biomass was composed of species with large size classes, which were replaced by 1995 by non-commercial species with a greatly decreased maximum length. Additionally, this shift led to the dominance of two species, whiting (*Merlangius merlangus*) and haddock (*Merlanogrammus aeglefinus*), both of which were not target species. Large size-class species such as spurdog (*Squalus acanthias*) and saithe (*Pollachius virens*), were either absent or exceedingly rare in this state.

The reasons given for differences in findings between these studies is the existence of a fishery for skates, rays and spurdogs in the North Sea, which likely meant that fishing prevented them from replacing exploited teleost species as it has done elsewhere (Greenstreet & Hall, 1996). Differences in the geography of the area analysed by Heath & Speirs (2011) may have prevented recruitment of some species from adjacent areas, whereas the lack of large individuals of round- and flatfish in McHugh et al. (2011) could be due to the fact that the surveys were conducted in shallow water. Greenstreet & Hall (1996) attributed the increase in low size classes to an increase in Norway pout (*Trisopterus esmarkii*), hypothesising that change in the pelagic systems, which were not considered in their study, could have caused that specie to increase. Declines in long rough dab (*Hippoglossoides platessoides*) and grey gurnard (*Eutrigla gurnardus*), however, could not be attributed to any direct effect, and were instead attributed to stochastic drift. Increases in *Scyliorhinus canicula*, however, were attributed to a high survivorship in trawls, which agrees with McHugh et al. (2011).

These are just three examples from a growing list of studies (e.g: Bailey et al. 2009; Daan et al. 2005; Philippart, 1998; Rice & Gislason, 1996; Rumohr & Kujawski, 2000; Walker & Heessen, 1996; Walker & Hislop, 1998). All have similar results. In other European studies, such as that of Jukic-peladic et al. (2001) in the Adriatic, these trends are again found to hold. The main changes there were found in the elasmobranch assemblage, with *S. canicula* increasing and small size-class species taking the place of elasmobranchs in the top percentages of the catch (Jukic-Peladic et al. 2001).

Despite differences in the changes over time in individual species, dominance and eveness, the above mentioned studies do show that the specie diversity in temperate shelf waters are temporally resilient to the effects of demersal trawling (Greenstreet & Hall, 1996). It is thereby not always correct to assume that trawling negatively affects specie diversity. This is true for the demersal fish assemblage. Effects on the benthic epi- and infauna may be more severe and may vary among regions (Atkinson et al. 2011; Jennings et al. 2006; Rumohr & Kujawski, 2000).

Studies on the Agulhas Bank

Studies have used the survey trawl data (1985 to present) from the Agulhas Bank extensively in order to monitor the abundance of target and bycatch species and provide management and biological information (Badenhorst & Smale, 1991; Leslie, 2008; Smale & Badenhorst, 1991; Walmsley-Hart et al. 1999; Yemane et al. 2008; Yemane et al. 2010). Although these studies generally follow the trends found in the international literature, they do not represent changes in abundance from baseline populations (Hutchings & Baum, 2005).

Only two other studies have been done using historical data on the Agulhas Bank: Griffiths (2000) and Yemane et al. (2004). Both studies focus on the linefish assemblage. The fisheries are spatially disjunct, with these studies focussing on the south eastern coast. However, there is an overlap of the species caught in the fisheries. Primarily, it is the trawl fishery that catches juvenile linefish, and this conflict has existed since even before the trawl fisheries opened (Gilchrist, 1898).

Findings in the linefish assemblage showed that the mean length of the size spectra on the South Eastern Cape has shifted from a system of many large fish to a state where small fish are more abundant. Additionally, two bio-geographical regions were identified by Yemane et al. (2004), one cool temperate region and a warm temperate, which had different responses to linefishing. The cool temperate region became dominated by two species, whereas the warm region shifted to a high eveness of species. Griffiths (2000) attributes this to the depletion of historically important and more desirable stocks and a subsequent shift to secondary linefish species. As in his study, catch composition remains fairly stable between the 1890's and the 1930's. However, there is also an indication of major change between the 1930's and the 1980's, which indicates a large shift in the Agulhas Bank system as a whole (Griffiths, 2000). This is comparable to what was found in my study, with a significant difference between the historical and recent time periods. Due to a lack of time-

series data, it is impossible to pinpoint exactly when this shift occurred. It may be worth examining this period in detail.

Other factors which may also affect abundance

Existing studies show that changes are often site- if not situation specific, and that there are often a range of variables that are involved besides fishing pressure.

McHugh et al. (2011) mention that there has been a recent change in the ambient water temperature in the North Sea area, which may have had an influence on the species investigated. However, the authors add that climatic influences are best understood when a time-series of data is available. This illustrates the problem of investigating environmental effects on fishing in the long-term. Most historical data (as in the present study) are only able to compare discreet periods due to interruptions in the conduction of the surveys. On the Agulhas Bank, there is evidence of some climatic change (Lutjeharms et al. 2001). The models governing the climatic research in this area, however, focus on the Benguela Upwelling and Agulhas Currents, and not the area of the Agulhas Bank. Lutjeharms et al. (2001) state that change according to the current statistical models predict intensification of the flow of the Agulhas current. This in turn would lead to a clearer thermocline formation on the inshore boundary of the Agulhas Current and the Agulhas Bank. This could potentially lead to an increase in productivity there (Gill & Schumann, 1979). The authors do caution as to the complexity of the predictions.

Apart from the potential climatic influences, some authors make a distinction between the direct removal of fish and secondary effects of trawling (predator removal). Using three surveys from the North Sea, Daan et al. (2005) looked at the small fish (low Lmax) species, as an increase in absolute abundance would be indicative of the removal of predation pressure, whereas it is clear that a decrease in large Lmax species would be a direct effect of fishing. Results indeed found the general decline of larger species, and increases in the smaller species, although there was some variability among surveys and areas. Results showed that without the introduction of a lag phase, correlations were not significant. However, when a time-lag was included, correlations were significantly positive in the small and medium size classes, and significantly negative for the large size class, with trends in the Lmax correlation following the same pattern. The authors conclude that indirect effects cause

small size-class fish to increase i.e. a reduction in predation pressure is the reason why increases in small size-class fish are so widespread in areas impacted by fishing.

A release from predation pressure may explain the potential rise in the lesser gurnards (*Chelidonychthyes capensis*). As mentioned in the second chapter, stocks of the larger gurnard species (*C. capensis* and *C. kumu*) are deemed to be stable. The increase in relative gurnard abundance could therefore potentially be attributed to a decrease in the predation pressure on the lesser gurnard.

Other increases of small size-class fish are restricted to horse mackerel and sole (*Cynoglossus spp*). All other species showing increases are comparatively large. Again, however, without time-series data, it will be difficult to separate climatic changes from secondary effects of trawling.

Could the declines of chondrichthyan species have been predicted using methods of vulnerability categorisation?

Several systems of classification systems are used by governments and other interest groups to highlight species that are in need of protection by legislature due to concerns about the further existence of the specie. Probably the most well known are the Union for Nature Conservation (IUCN, 2001) and the United States Endangered Species Act (U.S. Fish & Wildlife Service, 1973). They have become a relatively simple and cheap way of monitoring the status of species of conservation interest, and have hence become popular among scientists and managers alike.

Following this trend, Jennings et al. (1999) felt that the key to understanding the potential effects of fisheries lay in the biology of the species, which would lead to predictability of shifts in the ecosystem. However, their results of phylogenetic comparisons of related species revealed that fecundity was not a reliable predictor of fishing response at all. Instead, they state that it is sufficient (and more accurate) to use a simple length measurement to predict the response of non-target species to fishing.

The purpose of using the categorisation methodology developed by the American Fisheries Society (Musick, 1999), is to highlight species who may be at risk due to exploitation. Little work has been done on the risk categorisation of chondrichthyans specifically on the Agulhas Bank, and only two species have protective legislation (*Charcharodon carcharhias* and *Carcharhias taurus*).

A brief look at the declines and increases in this study show that both systems would have generally worked in this case. However, there is always an exception to the rule. The increase in *Callorhinchus capensis* goes against both categorisation methods of Jennings et al. (1999) and that of Musick (1999) in that it is a relatively large specie with relatively low fecundity compared to teleosts and co-geners have shown declines; yet, it has shown an increase in abundance. Most other species fit into both categorisation methods: smaller fish are at lower risk due to size and higher fecundity compared to larger fish.

As the purpose of these methods is not to certify which species will have which trends, but to highlight species which may show a significant change in abundance in the presence of fishing pressure, both systems would work. The fact that a specie breaks the forecast trend and increases should be even more of a highlight for more research.

Are chondrichthyans more at risk than teleost fish?

The problem faced in answering this question in the inshore trawl fishery (and other multi-species fisheries), is that chondrichthyans are all part of the bycatch assemblage. This bears with it major challenges in terms of quantification and management. Bycatch species are less likely to be recorded due to the high discard rate and lack of protective legislature. Hall et al. (2000), lists several fishery and bycatch conflicts around the world. Other studies include Shepherd & Myers (2005), who looked at the effects of fishing on small elasmobranchs in the Gulf of Mexico. Damalas & Vassilopoulou (2011) looked at chondrichthyan bycatch and discarding in the Aegean Sea, while Stobutzki et al. (2002), conducted a comprehensive assessment in a tropical prawn trawl fishery.

In light of all these studies and the described declines of chondrichthyans in them, one can infer that chondrichthyans are indeed more at risk. These studies highlight a general trend of the susceptibility of especially chondrichthyan bycatch species to fishing pressure. It also indirectly points to the need for comprehensive survey data where the entire catch is recorded, and none is discarded.

Although studies have analysed the trends of chondrichthyans under fishing pressure before, few have answered the question pertaining to the general susceptibility. Those that have attempted to, use certain criteria to categorise chondrichthyans. The relative abundance of the vast majority of the

chondrichthyans analysed here have indeed declined. These trends were confirmed by specie-specific univariate trends and comparison to trends analysed by Leslie (2008). It is quite clear, therefore, that chondrichthyans are indeed more susceptible to fishing pressure than teleosts. However, secondary effects may still have a large influence on affected species, and may manipulate them under the right conditions to their benefit.

A general review of the effects of fishing on chondrichthyans is given by Stevens et al. (2000). Direct effects are a decrease in abundance due to the removal of individuals, which is accompanied by a change in length-frequencies, often away from large individuals but sometimes reflecting a size restriction in the fishing gear (e.g: mesh size). While these lead to noticeable changes in the population parameters of teleost populations, Stevens et al. (2000) argue that there is little evidence for this in chondrichthyans. However, if continued over the long-term, these trends could possibly lead to the extinction of certain chondrichthyan species. This has been proven by Dulvy et al. (2000) in the North Sea.

Secondary effects of fishing on chondrichthyans can be broadly placed into three categories: predator removal, prey removal and competitive release. Jennings et al. (2006) state that the removal of predators will not increase the abundance of prey species, as bottom-up (environmental) effects have a greater effect on the ecosystem. While there is little evidence for prey depletion affecting chondrichthyans, competitive release has been shown to be a key result of chondrichthyan removal (e.g: Dulvy et al. 2000; Stevens et al. 2000).

This study was the first to concentrate on the historical abundances of chondrichthyans on the Agulhas Bank. It has shown significant changes in the chondrichthyan assemblage over the period of exploitation from the inshore trawl fishery. Although most trends can be attributed to the direct effects of fishing, secondary effects remain to be researched. Despite this, chondrichthyans were found to be more susceptible than teleost fish to the long-term effects of trawling.

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APPENDIX

Appendix: Lumping and assignment of scientific and vernacular names of those species analysed in the common grid blocks.

Species	Family	Order
Acanthocepola indica	Cepolidae	Perciformes
Acropoma japonicum	Acropomatidae	Perciformes
Aetobatus narinari	Myliobatidae	Rajiformes
Argyrosomus spp.	Sciaenidae	Perciformes
Argyrozona argyrozona	Sparidae	Perciformes
Arnoglossus spp.	Bothidae	Pleuronectiformes
Arothron immaculatus	Tetraodontidae	Tetraodontiformes
Atractoscion aequidens	Sciaenidae	Perciformes
Austroglossus spp.	Soleidae	Pleuronectiformes
Baardman	Sciaenidae	Perciformes
Bathyraja smithii	Rajidae	Rajiformes
Brama spp.	Bramidae	Perciformes
Callorhinchus capensis	Callorhinchidae	Chimaeriformes
Carcharhinus brachyurus	Carcharhinidae	Carcharhiniformes
Cheilodactylus spp.	Cheilodactylidae	Perciformes
Cheimerius nufar	Sparidae	Perciformes
Chelidonichthys spp.	Triglidae	Scorpaeniformes
Chirodactylus brachydactylus	Cheilodactylidae	Perciformes
Chirodactylus spp.	Cheilodactylidae	Perciformes
Chrysoblephus spp.	Sparidae	Perciformes
Congiopodus spp.	Congiopodidae	Scorpaeniformes
Cruriraja parcomaculata	Rajidae	Rajiformes
Cynoglossus spp.	Cynoglossidae	Pleuronectiformes
Dasyatidae spp.	Dasyatidae	Rajiformes
Dentex	Sparidae	Perciformes
Diplodus spp.	Sparidae	Perciformes
Dogfish	Squalidae	Squaliformes
Eel	Anguillidae	Anguilliformes
Electric skate	Torpedinidae	Torpediniformes
Fish unID	Fish unID	Fish unID
Forkbek *(Lithognathus lithognathus)*	Sparidae	Perciformes
Galeichthys spp.	Ariidae	Siluriformes
Galeocerdo cuvier	Carcharhinidae	Carcharhiniformes
Galeorhinus galeus	Triakidae	Carcharhiniformes
Gemfish *(Beryx spp)*	Berycidae	Beryciformes
Genypterus capensis	Ophidiidae	Ophidiiformes
Gonorynchus gonorhynchus	Gonorynchidae	Gonorhynchiformes
Grunter	Pomatomidae	Perciformes

Gymnura natalensis	Gymnuridae	Rajiformes
Halaelurus spp.	Scyliorhinidae	Carcharhiniformes
Haploblepharus edwardsii	Scyliorhinidae	Carcharhiniformes
Helicolenus dactylopterus	Sebastidae	Scorpaeniformes
Horsefish (*Congiopodus spp.*)	Congiopodidae	Scorpaeniformes
Hyperoglyphe spp.	Centrolophidae	Perciformes
Joss Fish	Callorhinchidae	Chimaeriformes
Lepidopus caudatus	Trichuridae	Perciformes
Lithognathus spp.	Sparidae	Perciformes
Lophius spp.	Lophiidae	Lophiiformes
Merluccius spp.	Merlucciidae	Gadiformes
Mud Soles	Cynoglossidae	Pleuronectiformes
Musselcrusher	Sparidae	Perciformes
Mustelus spp.	Triakidae	Carcharhiniformes
Myliobatis aquila	Myliobatidae	Rajiformes
Myripristinae spp.	Holocentridae	Beryciformes
Myxine capensis	Myxinidae	Myxiniformes
Narke spp.	Narkidae	Torpediniformes
Pachymetopon aeneum	Sparidae	Perciformes
Pachymetopon blochii	Sparidae	Perciformes
Pagellus bellottii natalensis	Sparidae	Perciformes
Paracallionymus costatus	Callionymidae	Perciformes
Penhaai	Squalidae	Squaliformes
Petrus rupestris	Sparidae	Perciformes
Pliotrema warreni	Pristiophoridae	Pristiophoriformes
Polysteganus undulosus	Sparidae	Perciformes
Pomadasys spp.	Haemulidae	Perciformes
Pomatomus saltatrix	Pomatomidae	Perciformes
Poroderma africanum	Scyliorhinidae	Carcharhiniformes
Poroderma pantherinum	Scyliorhinidae	Carcharhiniformes
Priacanthus spp.	Priacanthidae	Perciformes
Psychrolutes macrocephalus	Psychrolutidae	Scorpaeniformes
Pterogymnus laniarius	Sparidae	Perciformes
Raja spp.	Rajidae	Rajiformes
Rhabdosargus spp.	Sparidae	Perciformes
Rhinobatos spp.	Rajidae	Rajiformes
Sawfish	Pristidae	Pristiformes
Sawshark	Pristiophoridae	Pristiophoriformes
Scomberesox saurus scomberoides	Scomberesocidae	Beloniformes
Scophthalmus spp.	Scophthalmidae	Pleuronectiformes
Scyliorhinus capensis	Scyliorhinidae	Carcharhiniformes
Shark	Carcharhinidae	Carcharhiniformes
Sole	Soleidae	Pleuronectiformes
Solea spp.	Soleidae	Pleuronectiformes
Sphyrna spp.	Sphyrnidae	Carcharhiniformes

Spondyliosoma emarginatum	Sparidae	Perciformes
Squalus spp.	Squalidae	Squaliformes
Stromateus fiatola	Stromateidae	Perciformes
Synaptura marginata	Soleidae	Pleuronectiformes
Syngnathus acus	Sygnathidae	Sygnathiformes
Tetraodontidae spp.	Tetraodontidae	Tetraodontiformes
Tetrosomus concatenatus	Ostraciidae	Tetraodontiformes
Thyrsites atun	Gempylidae	Perciformes
Torpedo spp.	Torpedinidae	Torpediniformes
Trachurus capensis	Carangidae	Perciformes
Trichiurus lepturus	Trichuridae	Perciformes
Umbrina spp.	Sciaenidae	Perciformes
Zeus spp.	Zeiidae	Zeiformes